ISOLATING THE HARD POMERON

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Diffractive scattering in the presence of a large momentum transfer is an ideal place to study the pomeron in a region accessible to perturbative QCD calculations. Such studies have focused on 'rapidity gaps between jets'. We discuss the problems associated with this approach, and propose a new approach, in which we study double dissociation at high $|t|$. We conclude that this more inclusive study avoids many of the drawbacks of measurements involving gaps between jets.

1 Why look for the hard pomeron?

For almost 40 years, Regge theory has successfully parameterised our ignorance about the underlying dynamics of the strong interaction in long distance processes (i.e. the bulk of total hadronic cross sections). In contrast, perturbative QCD (pQCD), whilst outstandingly successful at describing short distance physics, has as yet been unable to "explain" Regge behaviour, as it must if it is to be regarded as the complete theory of the strong interaction. We are therefore faced with the unsatisfactory situation of having two theoretical frameworks, each describing the strong interaction in different kinematic regimes. Since, in Regge phenomenology, the pomeron, which in modern language has come to mean any strongly interacting colour singlet object with vacuum quantum numbers, is the object responsible for the high energy behaviour of total hadronic cross sections, a natural first step towards a QCD understanding of Regge theory would seem to be a pQCD understanding of the pomeron.

With this in mind, Mueller & Tang [1] suggested the study of the "rapidity gaps between jets" process, in which one looks for two high E_T jets with a rapidity gap between them. The jets guarantee that the momentum transfer across the rapidity gap is large and hence pQCD is applicable. Calculations have been performed within the leading logarithmic approximation (LLA) of BFKL [2] and predict an exponentially strong rise of the cross section with increasing gap size. However, with the completion of the next to leading logarithmic corrections [5], the magnitude of this rise has been thrown into some doubt, and it is therefore crucial that a precise experimental test of the theory is available. Unfortunately, the gaps between jets approach, whilst certainly showing a signal for a gap producing mechanism above the expectation from normal pQCD processes (at both the Tevatron and HERA [3 4 7 8]), falls short of delivering precise data. In this paper we discuss the drawbacks of the gaps between jets approach, and present a new, more inclusive experimental approach [6], which will provide data better suited for precise quantitative comparisons with theory.

2 The pomeron in QCD

We will focus on the situation at HERA, in which a quasi real photon radiated by the beam positron interacts with a proton. In this case, the photon behaves like a hadronic object, and a parton from the photon interacts with a parton from the proton. In the limit $-t \gg \Lambda^2_{\rm QCD}$ we can factorise the long distance physics into parton distribution functions and assume that the gap is produced by a single elastic parton-parton scattering, i.e. we can write

$$\frac{d\sigma(\gamma p \to XY)}{dx_\gamma dx_h dt} = F_\gamma(x_\gamma, -t) F_p(x_h, -t) \frac{d\hat{\sigma}(qq \to qq)}{dt} \tag{1}$$

where $F_i(x,\mu^2) = \frac{9}{4} g_i(x,\mu^2) + \Sigma_i(x,\mu^2)$ is a colour weighted sum over gluon and quark parton density functions for beam particle i. The fraction of the beam momentum carried by the struck parton is x and μ is the factorisation scale. The perturbative QCD dynamics lies in the cross-section for elastically scattering a pair of quarks: $d\hat{\sigma}(qq \to qq)/dt$. In the leading logarithm approximation, this is given by exchanging a pair of interacting reggeised gluons [2]. In the asymptotic limit $x_\gamma x_h W^2 \gg -t$ the cross-section is that computed by Mueller & Tang [1]:

$$\frac{d\hat{\sigma}(qq \to qq)}{dt} = (\alpha_s C_F)^4 \frac{2\pi^3}{t^2} \frac{e^{2\omega_0 Y}}{(7\alpha_s N_c \zeta(3) Y)^3} \tag{2}$$

where

$$\omega_0 = N_c \; 4 \ln 2 \; \frac{\alpha_s}{\pi}.$$

and Y is the rapidity difference between the outgoing partons from the hard scatter. The key feature is the exponential rise in the cross section with Y. This means that the larger the experimental reach in rapidity, the clearer the characteristic BFKL rise in the cross section becomes. A major drawback of the gaps between jets approach is the inability to access large rapidity differences. If two jets of cone radius one unit of rapidity must be contained within the calorimeters, and a typical calorimeter spans no more than eight units of rapidity, the reach in Y is clearly limited. Furthermore, the requirement of two jets with $E_t > 5$ GeV restricts $|t| > 25$ GeV^2, whereas the pQCD cross

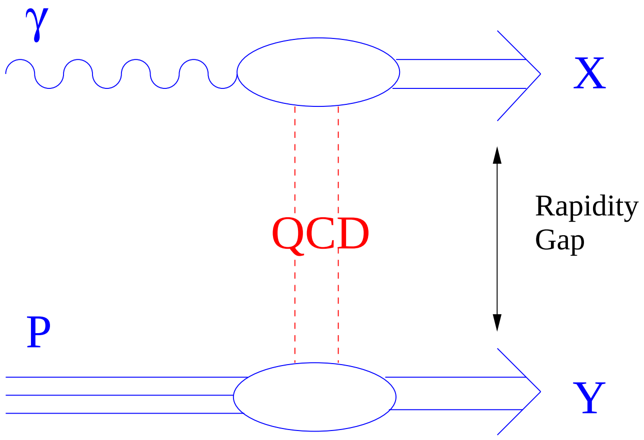

Figure 1: The generic "QCD pomeron" scattering process in photoproduction at HERA

section may well hold to $|t| \sim 1$ GeV^2. We are therefore throwing away the overwhelming majority of the events available for analysis. There should be a better way to investigate this region of 'high $|t|$ diffraction'.

3 A New Approach at HERA

A solution to both these problems has been suggested by Cox & Forshaw [6] . The hadronic final state is split by the largest rapidity gap in the event into two hadronic systems X and Y (Fig. (1)). In terms of the jet measurement, system X is the backward, or photon side jet and Y is the forward or proton side jet. The scattered electron is tagged in the electron tagger, limiting Q^2 to < 0.01 GeV^2. The entire kinematics of the event are constrained by the measurement of the scattered electron, giving the 4-vector of the photon, and the 4-vector of the X system, which at HERA is boosted into the detector and hence well measured. We now have the advantage that we can allow the Y system to move completely outside the detector, since we do not need to measure it, increasing the largest accessible gap size to over seven units of rapidity.

With the hadronic final state split into two systems as described above, it follows from Eq. (2) that [6]

$$\frac{d\sigma(\gamma p \to XY)}{dx_{\mathbb{P}}\,dt} \sim \left(\frac{1}{x_{\mathbb{P}}}\right)^{2\omega_0+2} F_\gamma(x_\gamma, -t) \qquad (3)$$

(a) (b)

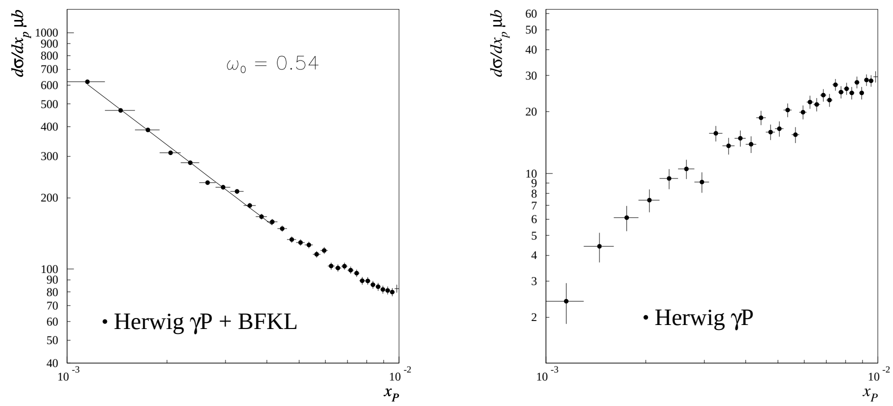

Figure 2: $\frac{d\sigma}{dx_{\mathbb{P}}}(\gamma p \to XY)$ at fixed W for HERWIG colour singlet + photoproduction (a) and photoproduction alone (b), for a luminosity of $\sim 2.5pb^{-1}$. Also shown in (a) is the value of ω_0 recovered from a $\frac{1}{x_{\mathbb{P}}}^{2\omega_0}$ fit shown as the solid line.

where $x_\gamma = -t/(x_{\mathbb{P}}W^2)$, $x_{\mathbb{P}} = (M_X^2 - t)/W^2$, W is the γp centre of mass energy and, since gap events are characterised by $M_X, M_Y \ll W$, the sample has been restricted by insisting that $M_Y \leq M_{Y\mathrm{cut}}$. It should be noted that this prediction is dependent only on the exponential form of Eq. (2), not the details of the leading order BFKL equation which gives the prediction for the pomeron intercept ω_0. This measurement therefore offers the possibility of measuring directly the hard pomeron intercept, 'to all orders' in the theory.

The Mueller & Tang colour singlet cross section has been implemented into the HERWIG 5.9 Monte Carlo [9], allowing a simulation up to hadron level including the background expected from fluctuations from non colour singlet photoproduction processes. The $x_{\mathbb{P}}$ distribution at fixed W is shown in figure 2 for both standard photoproduction and photoproduction with colour singlet exchange, for $W = 250$ GeV, $0 < M_y < 10$ GeV and $|t| > 4$ GeV^2. For the colour singlet sample, ω_0 is an input parameter into HERWIG, here chosen to be 0.61. In fact, Cox & Forshaw [6] show that Eq. (3) implies that, to a good approximation, $d\sigma/dx_{\mathbb{P}} \sim 1/x_{\mathbb{P}}^{2\omega_0}$. A fit for ω_0 to the measured $x_{\mathbb{P}}$ distribution is shown in Fig. (2a).

4 Conclusions

Results from CDF [3], D0 [4], ZEUS [7] and H1 [8] all show evidence of an excess of gap events at high $|t|$ over what would be expected from non-colour singlet exchange processes. The data, however, are not at present sufficient to allow precise quantitative comparisons between theoretical models. The new approach suggested by Cox & Forshaw [6] avoids many of the drawbacks of the 'gaps between jets' measurements, and provides a well defined cross section for comparison with theory.

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