NEW MEASUREMENTS OF INCLUSIVE DIFFRACTION AT HERA

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Two new diffractive measurements from HERA are described. ZEUS data on the diffractive structure function F_2^D at low Q^2 constrain the transition in diffraction from the perturbative high Q^2 region to the photoproduction limit. An effective pomeron intercept $\alpha_{I\!P}(0)$ is extracted from the energy dependence of the data and is compared with values from diffractive and inclusive ep interactions at lower and higher Q^2. An H1 analysis of photoproduced dijet events with low levels of hadronic activity between the jets demonstrates the presence of strongly interacting colour singlet exchanges at very high momentum transfer. The data are used to investigate the relative coupling strengths of this exchange to quarks and gluons.

1 Diffraction at HERA

Data from the HERA ep collider have led to considerable progress in the understanding of diffraction within QCD.[1] The HERA diffractive process can be viewed most generally as shown in figure 1. A photon of virtuality Q^2 (coupled to the electron) interacts with a proton at centre of mass energy W and squared four momentum transfer t to produce two distinct systems of masses M_X and M_Y at the photon and proton vertices respectively. The hermetic nature of the H1 and ZEUS detectors make it possible to control all five kinematic variables in figure 1 at some level.

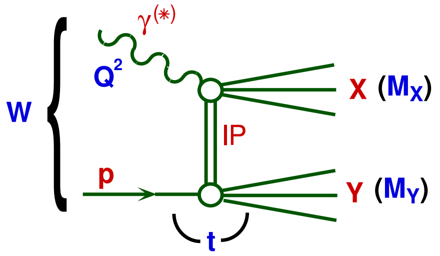

Figure 1. The generic HERA diffractive process of the type $\gamma^{(*)} p \rightarrow XY$.

Where both Q^2 and $|t|$ are small, the dynamics are similar to those of soft diffractive hadron-hadron scattering.[2] Where $|t|$ is small but Q^2 is large, perturbative QCD techniques have successfully been applied at the photon vertex. Under these circumstances, the virtual photon can be viewed as probing the structure of the diffractive exchange or 'pomeron' ($I\!P$).[3,4] The region in which $|t|$ is large is well suited to approaches that calculate the diffractive exchange itself perturbatively.[5] Each of these regions is interesting in its own right. The transitions between them are likely to be particularly revealing.

2 The Diffractive Structure Function at Very Low Q^2

Measurements of the semi-inclusive process $ep \rightarrow eXY$ at low M_Y and $|t|$ and finite Q^2 have generally been presented in the form of a diffractive structure function $F_2^D(\beta, Q^2, x_{I\!P})$, where $x_{I\!P}$ may be interpreted as the fraction of the proton longitudinal momentum transferred to the X system and β as the fraction of the exchanged momentum carried by the quark coupling to the photon. F_2^D has now been measured at HERA throughout a large part of the accessible $\beta - Q^2$ kinematic plane for $x_{I\!P} < 0.05$.[3,4,6]

Using their beam-pipe calorimeter (BPC) to detect and measure electrons scattered at very small angles, the ZEUS collaboration have recently released F_2^D data in the region $0.22 < Q^2 < 0.70$.[7] Diffractive samples are extracted both by direct tagging of leading protons in a set of Roman pot detectors inserted into the beampipe in the outgoing proton direction and by decomposition of the distribution of M_X measured in the main detector. The $x_{I\!P}(\equiv x/\beta)$ dependence of the data has been interpreted at fixed β and Q^2 in a Regge motivated model, whereby

$$x_{I\!P} F_2^D \sim A(\beta, Q^2)\ \ (1/x)^{2\overline{\alpha_{I\!P}(t)}-2}\ . \qquad (1)$$

The t averaged value of the effective exchange trajectory extracted by the M_X decomposition method is $\overline{\alpha_{I\!P}(t)} = 1.126 \pm 0.012$ (stat.) $^{+0.027}_{-0.032}$ (syst.). After correcting for the finite t values of the measurement, the value extracted for the intercept of this effective trajectory is shown in figure 2 together with other values from diffractive[2,3,4] and inclusive[8] ep measurements. The values from the inclusive data are extracted using

$$F_2 \sim B(Q^2)\ \ (1/x)^{\alpha_{I\!P}(0)-1}\ . \qquad (2)$$

In the inclusive case, the energy dependence clearly becomes stronger as Q^2 increases. A similar effect is suggested by the diffractive data. In photoproduction and low Q^2 electroproduction, the effective intercepts in the diffractive and inclusive cases are compatible. However, at the largest Q^2, they differ. In fact, it has been observed[4] that the energy dependences of the diffractive and inclusive cross sections are rather similar at large Q^2, in contrast to the expectation for a simple Regge pole in equations 1 and 2.

Figure 3 shows the Q^2 dependence of diffractive ZEUS data at fixed M_X and W, presented in the form of a $\gamma^* p$ cross section. As is the case for the inclusive cross section,[8,9] a transition takes place in the region of $Q^2 \sim 1$ GeV^2 between the high Q^2 scaling region and a low Q^2 region in which the cross section saturates.

3 Rapidity Gaps Between High p_T Jets in Photoproduction

Diffractive scattering where both $W^2/|t|$ and $|t|$ are large corresponds to a region where Regge asymptotics are applicable, yet the

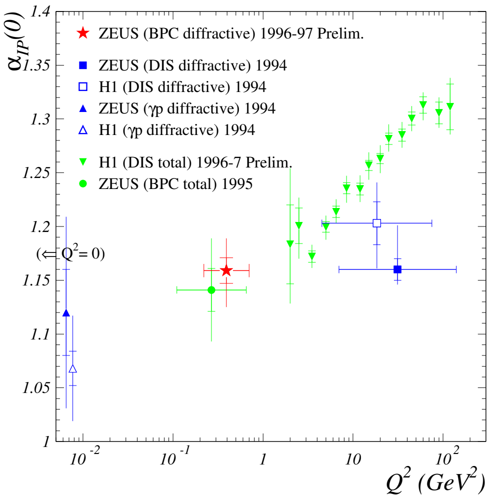

Figure 2. The effective pomeron intercept extracted from the energy dependence of selected inclusive and diffractive HERA data.

large scale set by $|t|$ encourages the use of perturbative QCD techniques.[5] The classic experimental signature is the appearance of regions devoid of hadronic activity between high p_T jets. A complication arises from possible re-interactions between the beam remnants, which can destroy the rapidity gaps in a non-perturbatively calculable manner. The H1 collaboration has devised a new means of presenting the data in an attempt to decouple the underlying event from the dynamics of the hard interaction.[10] Dijet events are studied where the two highest p_T jets have transverse momenta in excess of 6 GeV and 5 GeV respectively. As illustrated in figure 4, an event is classified as a 'gap' event if the sum $\not{E}_t^{jets}$ of all transverse energy not allocated to the jets yet in the pseudorapidity region between the jet axes is less than a specified value, E_t^{cut}. The fraction f of dijet events for which $\not{E}_t^{jets} < E_t^{cut}$ is measured as a function of E_t^{cut} and other kinematic variables. The E_t^{cut} dependence is sensitive essentially to the spectator interactions only and can be used to tune Monte Carlo simulations of the underlying event. The other kinematic variables are chosen to be sensitive to the dynamics of the hard interaction.

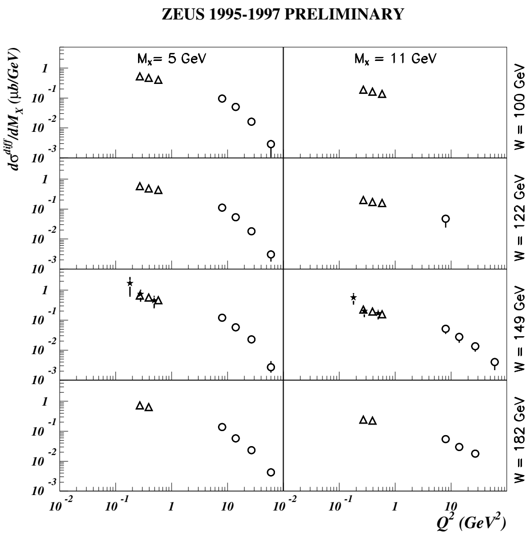

Figure 3. ZEUS measurements of the diffractive cross section, shown as a function of Q^2 at fixed M_X and W. The open triangles show the BPC data extracted from the M_X decomposition method. The stars show the BPC data extracted by direct leading proton tagging. The open circles are from a previous analysis.[4]

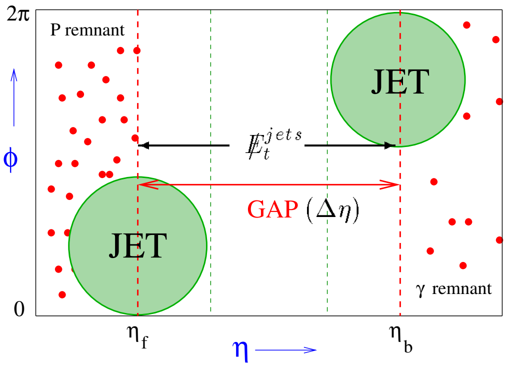

Figure 4. Illustration in $\eta-\phi$ space of the event topology and variable definitions in the rapidity gaps between jets analysis.

Choosing $E_t^{cut} = 1$ GeV, figure 5 shows the dependence of the gap fraction on the pseudorapidity separation of the two jets, $\Delta\eta$. The distribution is steeply falling at low values of $\Delta\eta$, where rapidity gaps arise dominantly from fluctuations in the hadronisation of standard photoproduction events. At the largest accessed values of $\Delta\eta$, the distribution becomes flatter, having a value similar to a previous ZEUS measurement[11], but significantly larger than that obtained in related measurements of $p\bar{p}$ scattering at the Tevatron.[12] The data are compared with four simulations. Those labelled 'PYTHIA' and 'HERWIG + JIMMY' are based on standard photoproduction matrix elements and contain models for multiple interactions. These simulations describe the data only at small $\Delta\eta$. The data show a clear excess over these models at large $\Delta\eta$, indicating a need for strongly interacting colour singlet exchanges at high $|t|$. Due to its highly peripheral t dependence,[13] the diffractive exchange studied in low $|t|$ diffraction at HERA[2,3,4] cannot explain the large rapidity gaps in dijet events. Two models that contain high $|t|$ colourless exchanges are compared with the data in figure 5. The first, labelled 'HERWIG + JIMMY + BFKL' includes a calculation of elastic parton scattering $qq \to qq^a$ at large momentum transfer,[14] based on the leading order BFKL equation with α_s set to 0.17. The second, labelled 'PYTHIA + ($\gamma \times 1200$)', models the colour singlet exchange using photon exchange, tuned to the data by scaling the calculated cross section by an unphysical factor of 1200. Since the BFKL exchange couples dominantly to gluons[b] whereas photon exchange couples exclusively to quarks, the latter model serves as a control to assess the sensitivity of the data to the nature of the external couplings. Both models containing colour singlet exchanges are able to describe the $\Delta\eta$ dependence of the gap fraction.

Since the relative sizes of the gluon and quark densities in the proton vary strongly with x, a variable that is more sensitive to the nature of the external couplings is the fractional momentum x_p^{jets} of the parton entering the hard scattering from the proton. x_p^{jets} is

[a] Antiquark and gluon couplings of the exchange are also implied
[b] The colour factors at the external vertices result in relative couplings of 81 : 16 for gluons compared to quarks.

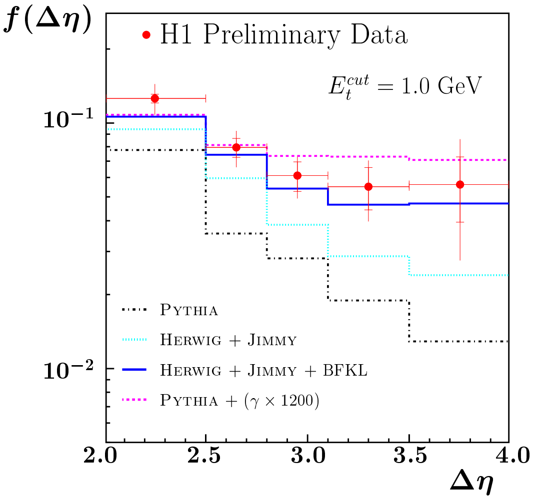

Figure 5. The gap fraction measured as a function of the pseudorapidity separation $\Delta\eta$ of the two leading jets.

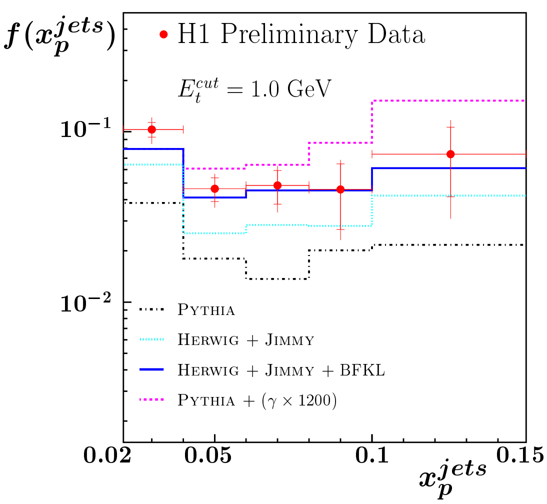

Figure 6. The gap fraction for events with $\Delta\eta > 2.5$, measured as a function of a hadron level estimator x_p^{jets} of the momentum fraction of the parton from the proton entering the hard scattering.

reconstructed from the total $E + p_z$ of the di-jet system[10]. The dependence of the gap fraction on x_p^{jets} is shown in figure 6 for the region $\Delta\eta > 2.5$, again with $E_t^{cut} = 1$ GeV. There is a signal above standard photoproduction predictions at all values of x_p^{jets}. The 'HERWIG + JIMMY' and 'PYTHIA + $(\gamma \times 1200)$' predictions differ in shape. The shape of the data distribution is more similar to the BFKL than to the photon exchange model, suggesting that the data contain a significant fraction of couplings to gluons, which at the present level of precision can be described by the BFKL calculation. Improved statistics are required before firm conclusions can be drawn.

Acknowledgments

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