Diffractive structure functions in DIS

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Abstract: A review of theoretical models of diffractive structure functions in deep inelastic scattering (DIS) is presented with a view to highlighting distinctive features, that may be distinguished experimentally. In particular, predictions for the behaviour of the diffractive structure functions $F_2^D, F_L^D, F_2^{D(\mathrm{charm})}$ are presented. The measurement of these functions at both small and high values of the variable β and their evolution with Q^2 is expected to reveal crucial information concerning the underlying dynamics.

1 Models of hard diffractive structure functions in DIS

It is natural to start with a definition of what we mean by the terms 'hard' and 'diffractive' when applied to scattering of electrons and protons. High energy scattering processes may be conveniently classified by the typical scales involved. By hard scattering we mean that there is a least one short distance, high momentum, scale (e.g. high p_T-jet, boson virtuality, quark mass) in the problem that gives one the possibility of using factorization theorems and applying perturbative QCD. In case of diffractive DIS this is the photon virtuality, Q^2, however this hard scale is not necessarily enough and indeed QCD factorization may not even be applicable to all hard diffractive scattering in DIS (see [1, 2, 3] for discussions and refs). It has been shown to be applicable to diffractive production of vector mesons initiated by a longitudinally polarized photon [4]. For the time being we will use the definition, due to Bjorken, that a diffractive event contains a non-exponentially suppressed rapidity gap. Rapidity is the usual experimental variable related to the trajectory of an outgoing particle relative to the interaction point: given approximately by $\eta \approx -\ln(\tan(\theta/2))$ (in a cylindrical system of co-ordinates centered on the interaction point, with the z-axis along the beam pipe and polar angle θ). This rather obscure sounding definition results from the fact that within perturbative QCD large rapidity gaps (LRG) *are* suppressed because a coloured particle undergoing a violent collision will emit radiation that would fill up the gap. The suppression factor increases with the interval of rapidity but it's absolute magnitude for diffractive processes in DIS is uncertain. An additional source of rapidity gap supression comes from an overall damping factor associated with multiple interactions. The amount of damping is found to be much smaller in DIS than that typical for soft processes (e.g. proton proton collisions see [5]) making LRG events more likely.

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Theoretically, for 'diffractive' electron proton scattering in DIS one must observe the proton in the final state. In practice this is very difficult for HERA kinematics since the highly energetic scattered proton disappears down the beam pipe in most events. This means that the current measurements also contain contributions from interactions in which the scattered proton dissociates into higher mass states. This uncertainty is considerably alleviated by the advent of the Leading Proton Spectrometer (LPS) which will provide crucial information about diffraction (for the first data from the LPS see [6]). The significance of the difference between the experimental working definition of diffraction and the theoretical one is an interesting but as yet unresolved problem (it is certainly possible to produce large gaps in rapidity in 'non-diffractive' processes, e.g. via secondary trajectory exchanges).

Such LRG events occur naturally in processes known to be governed by soft processes (e.g proton anti-proton scattering at high energies). This is explained naturally in the context of Regge theory : at high enough energies one reaches the so-called Regge limit ($s \gg t$ and $s \gg$ all external masses) and *all* hadronic total cross sections are expected to be mediated by Pomeron exchange and to exhibit *the same* energy behaviour. This expectation is born out by the data (see e.g. [7]), which shows that a wide variety of high energy total elastic cross sections have the same energy dependence which is attributed to the trajectory of the soft pomeron. The energy dependence for diffraction in these processes is discussed in e.g. [8].

Scattering of virtual photons and protons at small enough x corresponds to the Regge limit of this subprocess ($\hat{s} \gg \hat{t}$, $\hat{s} \gg Q^2, M^2_{\rm Proton}$). It is natural to ask if the diffractive events observed in the DIS sample also exhibit the universal behaviour even though we are now considering off-shell scattering for which, strictly speaking, Regge theory does not necessarily have to apply. One of the reasons why hard diffraction at HERA at small x is so interesting is that as x decreases, for fixed large Q^2 there should be a transition between the hard short distance physics associated with moderate values of x and the physics of the soft pomeron which is widely believed to dominate at very small x. It is a theoretical and experimental challenge to establish whether LRG events in DIS in the HERA range are governed by hard or soft processes or whether they are actually a mixture of both. The purpose of this report is to discuss the current theoretical models for diffractive structure functions in an attempt to address this problem, and, in particular, to outline the benchmark characteristics of the various approaches to facilitate the search for appropriate experimental tests.

In analogy to the total DIS cross section, the diffractive cross section in DIS can be written,

$$\frac{d\sigma^D}{dx_{\mathbb{P}}dtdxdQ^2} = \frac{4\pi\alpha^2_{\rm e.m}}{xQ^4}\left[1 - y + \frac{y^2}{2[1+R^D(x,Q^2,x_{\mathbb{P}},t)]}\right] F_2^D(x,Q^2,x_{\mathbb{P}},t) \tag{1}$$

where D denotes diffraction, $R^D = F_L^D/(F_2^D - F_L^D)$ and $y = Q^2/sx$; $t = 0$ is usually assumed since the cross section is strongly peaked here.

Ingleman and Schlein [9] suggested on the basis of expectations from Regge theory that the diffractive structure functions could be factorized as follows:

$$F_2^D(x,Q^2,x_{\mathbb{P}},t) = f(x_{\mathbb{P}},t)F_2^{\mathbb{P}}(\beta,Q^2,t), \tag{2}$$

where Q^2 is the photon virtuality, $x_{\mathbb{P}}$ is the fraction of the proton's momentum carried by the diffractive exchange and t is the associated virtuality, $\beta = Q^2/(M_x^2+Q^2) = x/x_{\mathbb{P}}$, with M_x^2 the mass of the diffractive system. The last relation for β in terms of x, the Bjorken variable, is a good approximation but only holds for negligible t and proton mass [10]. Due to lack of information on the remnant proton both $x_{I\!P}$ and t can only be estimated indirectly or have to be integrated out.

The 1993 HERA data [11, 12, 13] confirmed the presence of events with large rapidity gap between the proton direction and the nearest significant activity in the main detector, in the total DIS cross section at the leading twist level (i.e. this contribution persisted to high values of Q^2). These events constitute approximately 10 % of the total sample (compared to $\sim 40\%$ in photo-production). As has been known for many years and as Bjorken has recently pointed out [14] the fact the diffractive cross section is present in the total sample as a leading twist effect (i.e. it 'scales') at large Q^2 and small x does not necessarily imply that the mechanism that creates these events is point-like. For a careful discussion of the kinematics of hard and soft diffraction in a variety of different reference frames see [15].

The observed events were also not inconsistent with the Regge factorization of eq.(2). Since the cross section had the same power-like $x_{I\!P}$ dependence (in f) over a the wide range of (β, Q^2) that were measured it was tempting to postulate that a single mechanism or 'exchange' was responsible for these events. The presence of the gap tells us that this object is a colour singlet and since the centre of mass energy was very high, the exchanged object became known as the 'Pomeron'. From this observation it is natural to ask, following [9], if the partonic content of this 'particle' may be investigated by changing β and Q^2, with β interpreted as the momentum fraction of the pomeron carried by the struck parton; f in this picture is interpreted as 'the flux of pomerons in the proton'.

This approach has led to a plethora of theoretical papers in which the parton content of the Pomeron at some small starting scale, Q_0^2, is treated in various physically motivated ways (relying strongly on Regge theory). The DGLAP [16] equations of perturbative QCD (to a given logarithmic accuracy) are then used to investigate the evolution with Q^2 of this parton content. Formally the use of the DGLAP equations is inapplicable for the description of diffraction because the presence of the gap makes it impossible to sum over all possible final hadronic states. Their use in this context is at the level of a plausible assumption. In some papers an analogy is drawn with the proton [10, 17, 18] and a momentum sum rule may be imposed on the parton content. Others models [10, 19, 20] take the view that that the Pomeron may be more like the photon and so can have, in addition, a direct coupling to quarks within the virtual photon. Although it is no longer clear once a direct coupling has been introduced whether the concept of a Pomeron structure function has any meaning.

Fits [10, 17, 21] to the 1993 data on diffraction reveal a partonic structure that is harder (more partons at high β) than the proton and that gluons contain a large fraction of pomeron momentum (up to 90 %) with a large fraction of these at high β. Clearly in a quantitative sense such statements will depend on the physical assumptions used to parameterize the input distribution. However qualitatively these statements are reasonable. The paper of Gehrmann and Stirling [10] is particularly useful in discussing Pomeron structure function models in that it discusses and compares two models: model 1 which has only resolved component and imposes a momentum sum rule on the parton content and model 2 which also allows a direct coupling of the Pomeron to quarks. This leads to rather different predictions for the Q^2 evolution of these two models (see curves labelled 'GS(I), GS(II)' in fig.(1)). Model 1 evolves in a way familiar to the evolution of the proton structure function in QCD, i.e. as Q^2 increases there is a migration of partons from high to low β. In model 2, as a result of the direct coupling of the pomeron to quarks (at '$\beta = 1$'), the high β distribution is supplemented and, provided the direct component is large enough, one expects an increase of parton densities with Q^2 over the whole β range, which is also an expectation of the boson-gluon fusion model of [22] (see fig.(1)).

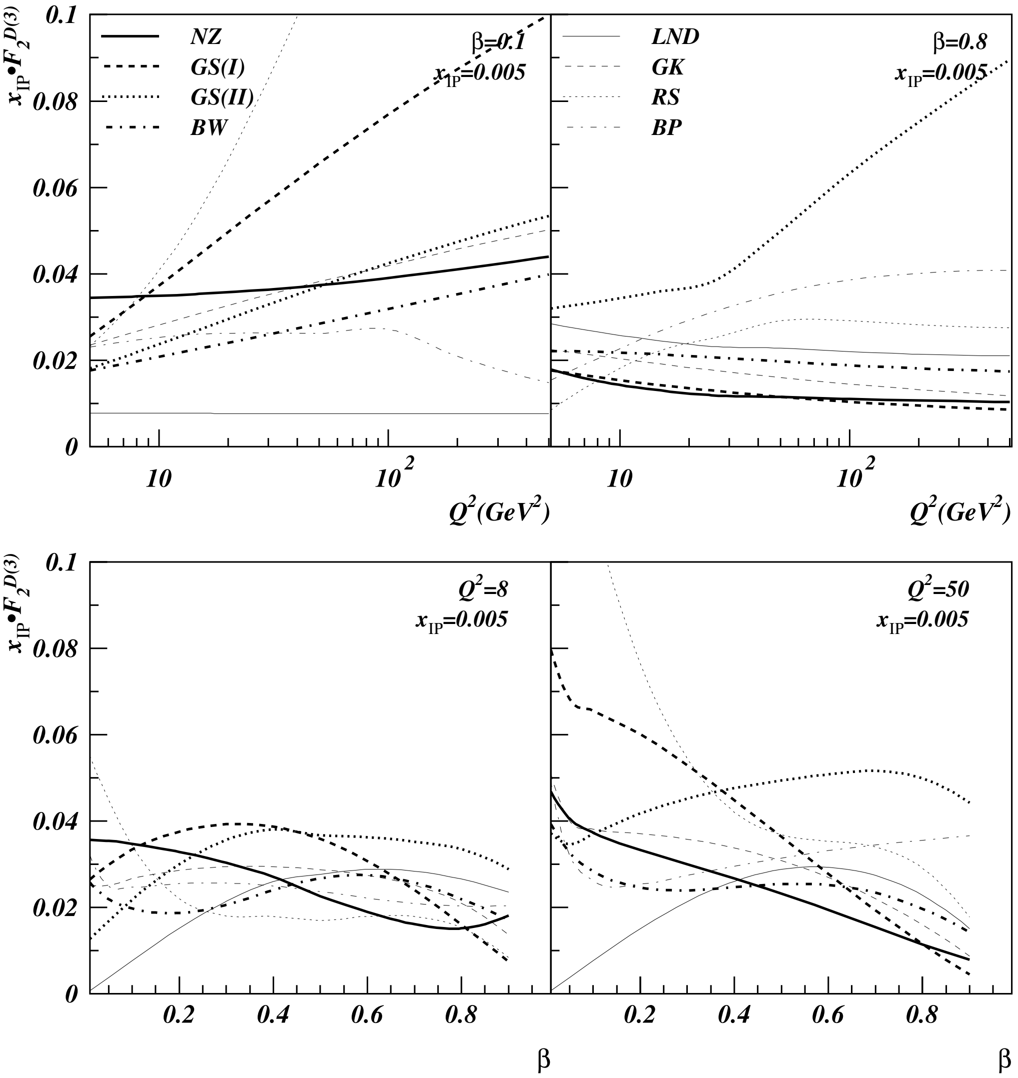

Figure 1: *Distribution of $x_{\rm I\!P} F_2^D(\beta, Q^2, x_{\rm I\!P})$ as a function of β and Q^2, at fixed $x_{\rm I\!P} = 0.005$, for various models. For key assignments - see text.*

The high gluon content of the pomeron that comes out of the LO QCD factorizable pomeron models indicate that the pomeron structure R-factor, $R^D(\beta, Q^2, x_{\rm I\!P}) = F_L^D(\beta, Q^2, x_{\rm I\!P})/F_T^D(\beta, Q^2, x_{\rm I\!P})$, where $F_T^D = F_2^D - F_L^D$, may be considerably bigger ($R^D \sim 1$) than that for the proton ($R^p \sim O(\alpha_s)$). Clearly in order to provide a theoretically consistent prediction for F_L^D a NLO QCD calculation is required. Such a calculation has been performed by Golec-Biernat and Kwiećinski [17] who consider a model with resolved partons in the pomeron subject to a momentum sum rule. For high β, R is small in such models but it can reach 0.5 for $\beta < 0.1$. It has a much softer dependence on β than F_2^D (see 'GK' in figs.(1,2)).

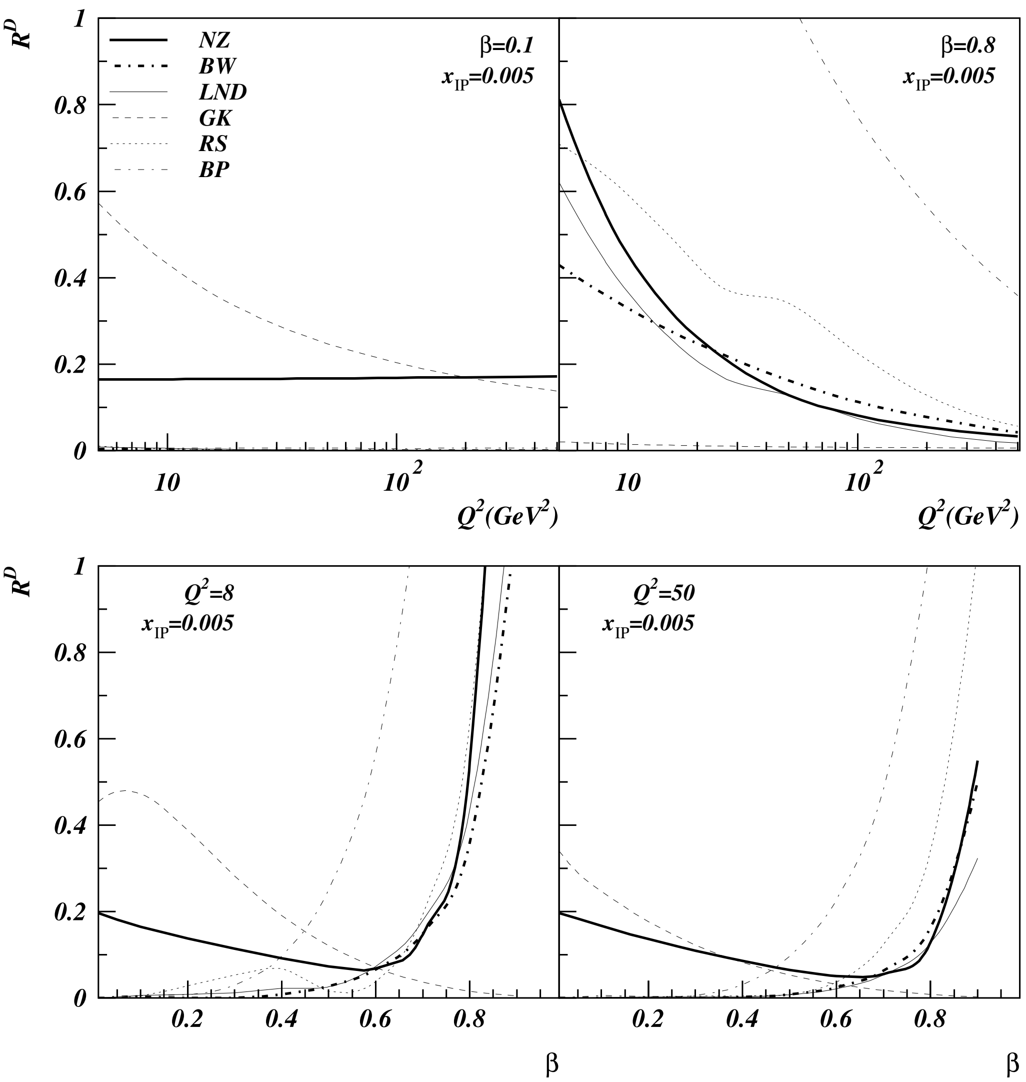

Figure 2: R^D *as a function of* β *and* Q^2 *for* $x_{\mathbb{P}} = 0.005$*. The pomeron structure function model 'GK' differs markedly from the two gluon exchange models 'NZ,BW, LND,RS,BP' at high and low* β*. Of these, those based on the dipole approach to BFKL, 'NZ,BP', produce markedly different* β *and* Q^2 *behaviour to 'RS,BW,LND'.*

This picture of the pomeron structure function has been discussed in detail elsewhere and will not be repeated in further detail here. For a lucid account of this picture and of the 1993 data see [21]. The latest results from H1 [23, 24] on the 1994 data (which has a factor of 10 increase in statistics and covers a broader kinematical range) suggest that single particle factorization no longer holds over the full kinematical range and that particularly for small β it breaks down, i.e. f in eq.(2) become β (but not Q^2) dependent. A possible explanation of this is that sub-leading Regge exchanges play an important rôle [23, 24, 25].

The paper by Ellis and Ross [26] calls into question the validity of these parton model approaches using kinematical arguments concerning the virtuality of the struck parton. They stress the importance of measuring diffractive events at high β and predict a slow power-like increase with Q^2 in this region in contrast to the logarithmic decrease that may expect from a naive QCD evolution.

This and others models are, broadly speaking, similar in spirit to the old aligned jet model (AJM), which is a kind of parton model approximation to the wavefunction of the photon (see [14, 15] and refs.), and it's QCD improved formulation (see [27] and refs.). Consider virtual-photon proton scattering at high energies (small x) in the proton's rest frame. In this frame the virtual photon, whose energy, q_0, is the largest scale, fluctuates into a $q\bar{q}$ at a large distances, $l_c = 1/2M_p x = q_0/Q^2$, from the proton. As Ioffe [28] observed many years ago these large distances are important in determining the DIS structure functions. For the HERA energy range this 'coherence length' can be as large as 1000 Fm. In other words, at enough high energies we may consider DIS as the interaction of the quark anti-quark pair with the proton. The transverse size of the pair on arrival at the proton is $b_T^2 \approx 1/k_T^2$.

In the configuration in which one of the quarks carries most of the momentum of the photon a large transverse distance develops between the fast and the slow quark by the time it arrives at the proton. This large system, in which the pair is initially 'aligned' along the direction of the original photon, essentially interacts with the proton like a hadron. This aligned configuration gives a leading twist contribution to F_2 and F_2^D, the latter being interpreted as the fraction of events where the produced pair is in a colour singlet state. Since the slow quark is almost on shell, the AJM is similar to the parton model and there is no leading twist contribution to F_L from this configuration.

In the configuration in which the momentum is shared more equally the quarks can stay closer together in transverse space and may interact with the proton perturbatively. These configurations contribute at leading twist to $F_2(x, Q^2)$ and $F_L(x, Q^2)$. In the former the integration over the momentum fraction leads to the logarithm in Q^2 (coming directly from the box diagram). For such small configurations colour transparency phenomena are expected: the emission of initial and final state radiation is suppressed [27].

A semi-classical calculation [29, 30] in which the proton is treated like a classical background field, leads to results very similar to those of the AJM. Working in the proton's rest frame, one considers the interaction of different kinematical configurations of the highly energetic partons in the virtual photon with the soft colour field of the proton. These interactions induce non-abelian eikonal factors in the wavefunctions of the partons which can lead to diffractive final states. In [30] the addition of gluon to the final state is considered. Leading twist diffractive processes appear when at least one of the three partons has a small transverse momentum and carries a small fraction of the longitudinal momentum of the proton. The other two partons may have large transverse momentum, this means they stay close together as they move through the proton, acting effectively as one parton. This high k_T jet configuration, produces the only leading twist contribution to F_L^D at this order (which is constant) and $\ln Q^2$ enhancement of F_2^D. This signals that F_2^D also has leading twist contribution from the configuration in which all the transverse momenta are small. Several qualitative phenomenological predictions come out of this picture. One expects the ratio F_2^D/F_2 to decrease like $\ln Q^2$ and there to be fewer high-p_T jets in F_2^D than in F_2 (they appear only at order α_s in the former). Leading twist diffraction appears at order α_s in F_L^D which will be dominated by jets.

Buchmüller and Hebecker [22] present a model of diffraction in DIS based on the dominant process being boson gluon fusion, with the colour singlet state being formed by soft colour interactions (SCI). The main point is that diffractive and non-diffractive events differ only by

SCI, the kinematics are expected to be similar since one gluon carries most of the momentum of the exchanged system. This idea has also been developed in [31, 32] which provides a Monte Carlo simulation of SCI.

The simplest QCD model for diffractive exchange is a pair of t-channel gluons in a colour singlet state. Such an exchange is a common feature of many models [33, 34, 35, 36, 37, 38, 39] and leads to a diffractive structure functions which are proportional to the gluon density squared. The dynamical content of these models differ in the treatment of QCD corrections and choice of gluon density and will be discussed in more detail below.

It may be possible to distinguish these models from those in which soft colour interactions play a rôle [29, 22, 30] by comparing $F_2^D(x, Q^2, x_{I\!P})$ with $F_2(x_{I\!P}, Q^2)$ for fixed Q^2 and intermediate β. For the latter the following scaling relation is predicted:

$$F_2^D(x, Q^2, x_{I\!P}) \simeq \frac{C}{x_{I\!P}} F_2(x_{I\!P}, Q^2) \tag{3}$$

where C is a constant.

In [33] where diffraction is governed by two gluon exchange one expects this behaviour to be multiplied by a factor $x_{I\!P}^{-\lambda}$, where $\lambda \geq 0.08$ and will depend on k_T^2 (see below). In the dipole approach to BFKL [38, 39], in which the dipoles couple via two gluon exchange a similar result is expected but with a larger power $x_{I\!P}^{-\Delta}$, $\Delta \equiv \alpha_{I\!P} - 1 = 12\alpha_s \ln(2)/\pi$ possibly softened by inverse powers of logarithms in $1/x_{I\!P}$ [38, 40]. Of course, in this case, the individual energy dependences of F_2 and F_2^D is expected to be a lot harder.

In the perturbative QCD approach advocated by Bartels and Wüsthoff [33] the coupling of the pomeron to the hadronic final state can be derived without any additional parameters except the strong coupling. The following ansatz is used for the unintegrated gluon density:

$$\psi(x, k_T^2, Q_0^2) \sim \frac{1}{k_T^2 + Q_0^2} x^{1-\alpha_{I\!P}(Q^2)}, \tag{4}$$

with the effective scale-dependent pomeron intercept (which explicitly, albeit mildly, breaks the factorization of eq.(2) since it depends of Q^2) $\alpha_{I\!P}(Q^2) = 1.08 + 0.1\ln[\ln(Q^2/1\text{GeV}^2) + 3]$ for $Q^2 > 0.05\text{GeV}^2$ and 1.08 below this. This gluon density is then fitted to the available data on F_2. Predictions for the diffractive cross section (which is proportional to $[\psi(x_{I\!P}, k_T^2, Q_0^2)]^2$ integrated over k_T^2) with $q\bar{q}$ and $q\bar{q}g$ in final state are then presented over a wide range of β. Now the relevant scale in $\alpha_{I\!P}$ is the virtuality k_T^2.

In the limit $\beta \to 1$ the longitudinal contribution, which is formally 'higher twist', is finite so is expected to dominate over the transverse part which goes like 1 - β. This highlights the fact that the concept of 'twist' must be applied very carefully in diffraction - contributions which naively appear higher twist may in fact dominate at high Q^2 in certain regimes. With an additional gluon in the final state one finds a $(1-\beta)^3$ behaviour at large β. For small β this configuration dominates and the cross section diverges like $1/\beta$. In summary, a characteristic β spectrum is found that shows that emission of the additional gluon is bound to the small β region whereas the large β is dominated by the longitudinal photon. Numerical results, labelled 'BW', using the ansatz of eq.(4) for F_2^D, and R^D as function of β and Q^2 are shown in figs.(1,2).

The large mass, small β or triple Regge regime ($s \gg M_x^2 \gg Q^2 \gg \Lambda_{QCD}^2$) has also been investigated in detail by Bartels and Wüsthoff (see [41, 42, 43] and refs). Theoretically the emergence of a 4 gluon t-channel state which builds up the large diffractive mass is expected. Experimentally, this region is hard to investigate since the requirement of a large mass tends to close up the rapidity gap making it difficult to distinguish experimentally from the non-diffractive background and also because the diffractive final state may not be fully contained in the main detector. This situation is improving now that the first data collected with the LPS is becoming available [6]. For the purpose of this report we will discuss expectations in the not-too-small β regime.

Diehl [34] has calculated the contribution of $q\bar{q}$ in the final state to the diffraction cross section in the non-perturbative two gluon exchange model of Nachtmann and Landshoff [36, 44]. Numerical predictions for this model (applicable for not-too-small β), labelled 'LND', are shown in figs.(1,2,3). This model predicts a relatively small contribution of charm in diffraction (less than 10 % over a wide range of $x_{\mathbb{P}}, \beta, Q^2$).

The high β, small mass regime of diffraction is considered explicitly in [37] who work in co-ordinate space of the transverse distance between the quark and the anti-quark. They claim that at high enough β (≥ 0.4) only the $q\bar{q}$ contributes (in agreement with [33]) and that for $\beta \geq 0.7$ diffractive scattering from the longitudinal photon dominates for which only small distances ($b_T \sim 1/Q$) contribute. The effective scale of the gluon density relevant to diffraction is $k_T^2/(1-\beta)$ (see also [45]) which is clearly hard for high β. This implies that for high β (see fig.(2)) R^D becomes greater than unity in sharp contrast to the Pomeron structure function model of [17]. For the transverse photon distances of $b_T \sim 1\mathrm{GeV}^2$ dominate which is used to justify the use of perturbative QCD and the use of evolution equations, using GRV input distributions, for the diffractive structure functions.

The series of papers by Genovese, Nikolaev and Zakharov [46, 47, 48, 49] provides a model for diffraction inspired by the QCD dipole approach [50, 39, 51] to the generalised BFKL [52] equation. In [48] they strongly reject the factorizable pomeron model and instead suggest that a two component structure function for the pomeron with valence and sea partons having different pomeron flux factors. The absolute normalizations of these components of the diffractive structure function are substantially the same as evaluated in 1991 [39], before the HERA data have become available. In recent papers for this Regge factorization breaking model specific predictions for F_L [46] and charm [47] are given (see 'NZ' in figs.(1,2,3)).

The curves, labelled 'RS', shown in figs.(1,2,3) are from a Monte Carlo simulation developed by A.Solano and M.Ryskin, for the dissociation of the virtual photon to two and three jets [53]. The formulae used are the same as those in the LMRT [35] model but use a GRV [54] gluon distribution and a simplified version of the NLO corrections.

Bialas and Peschanski also present predictions for hard diffraction [38, 40] based on the QCD dipole picture of the BFKL equation. In this picture they find that most of the diffractive cross section comes from the interaction of $q\bar{q}$ pairs whose transverse size is of the order of the target size as seen by the virtual photon. The perturbative QCD prediction is enhanced by the BFKL resummation and by the number of dipole configurations in the initial proton state. In the factorized picture they find a strong $x_{\mathbb{P}}$ dependence modified by log corrections. They expect R^D to be a strongly varying function of β and to go above unity for large β. The number of diffractive events increases with Q^2 over the whole range. At small β, i.e. large masses, they expect a scaling violation to be similar to that seen in F_2 at small x. Predictions of this model for F_2^D and R_D have been presented recently [55] and are shown, labelled 'BP', in figs.(1,2).

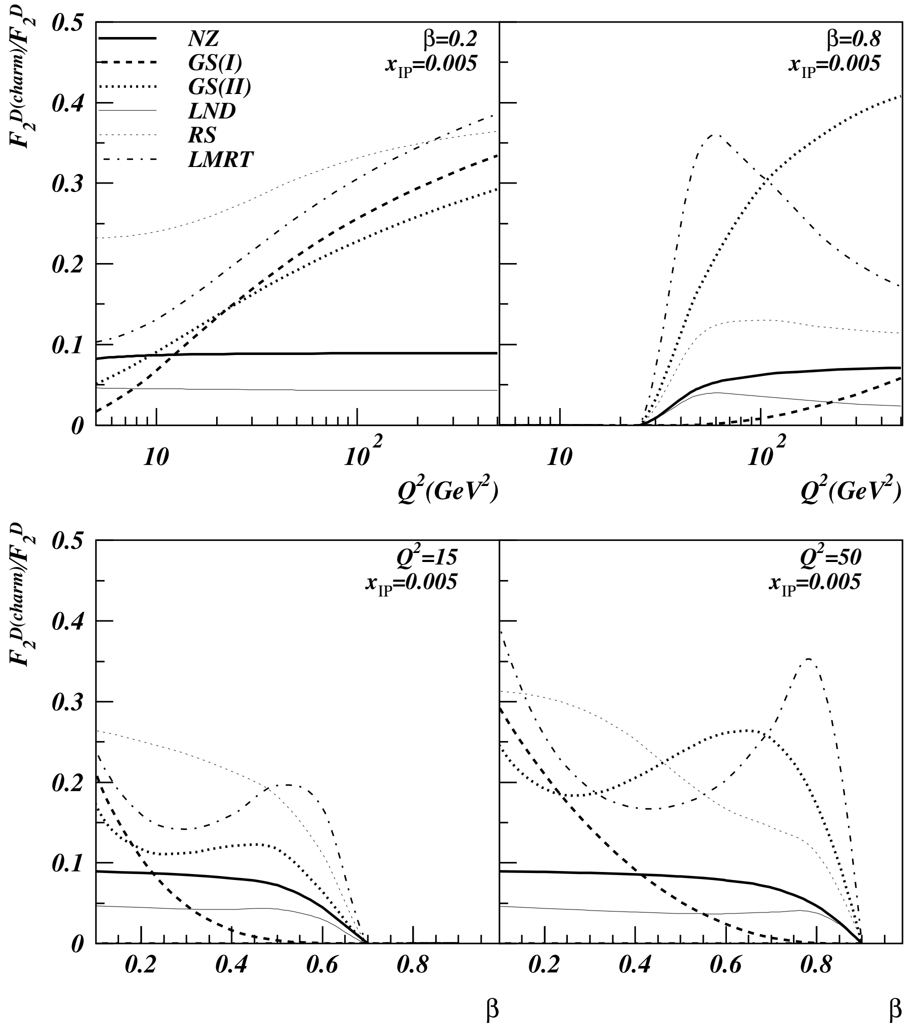

Figure 3: *Predictions for the charm content in diffraction, as a fraction on the total diffractive sample, as a function of β and Q^2 for $x_{\mathrm{IP}} = 0.005$. The maximum value of β reflects the charm threshold and increases with Q^2.*

2 F_2^D (Charm)

The ratio of charm events observed in the diffractive structure function is in principle a very good test of the hardness of the processes feeding the $c\bar{c}$ production. Clearly a measurement of the β and Q^2 spectra for these charm events will provide a lot more information.

If hard QCD dominates in diffraction, i.e. the transverse momenta of the $q\bar{q}$ in the loop are large, $k_T^2 \sim Q^2$, the relative yield of charm in diffraction is determined by the electric charges of the quarks and should be about 40 %. In the Pomeron structure function models of [10] the charm contribution comes from boson gluon fusion and is indeed large. Model 2 predicts that it should also be large at high β in comparison to model 1 (compare 'GS(I)' and 'GS(II)' in fig.(3)). Also since diffraction is a higher twist effect one would expect the $F^{D(\mathrm{charm})}/F^{(\mathrm{total\ charm})}$ to decrease quickly as a function of Q^2.

In the naive AJM, since the quark transverse momenta are small, one would expect a very small charm content. Within the QCD-improved AJM this may be expected to increase with Q^2 and for sufficiently high Q^2 the charm contribution to diffraction should approach that anticipated from hard physics.

The early paper of Nikolaev and Zakharov [49], predicts that the diffractive contribution to open charm is around 1 %. In a recent paper [47], they present predictions for the charm contribution to diffraction and suggest a very steep rise at small $x_{\mathbb{P}}$ strongly breaking Regge factorization; at $x_{\mathbb{P}} = 0.005$ this leads to a charm content of about 10 % (see 'NZ' in fig.(3)).

In a numerical study of the influence of the small k_T region in the BFKL equation, in [56], it is shown that the dominant contribution to diffraction comes from the region of small transverse quark momenta, even for large Q^2. This would seem to favour a small charm contribution in this model.

The LMRT approach [35] is based on the same Feynman graphs for $\gamma \to q\bar{q}$ and $\gamma \to q\bar{q}g$ dissociation as [33, 37, 41, 42] and [37, 39, 46, 47, 48, 49, 51]. [2] However in the LMRT case the most realistic MRS(A') gluon distribution (which fits all the present data) were used and the main NLO corrections, including an estimate of the K-factor in the $O(\frac{\alpha_s}{\pi}\pi^2)$ approximation, were taken into account. Thanks to the large anomalous dimension γ of the gluon structure function $g(x, k_T^2) \propto (k_T^2)^\gamma$ at small $x = x_{\mathbb{P}}$ the infrared divergence is absent from the k_T-integral and, even for the transverse part originated by the light quarks, the dominant contribution comes mainly from small distances (see also [37]) and doesn't depend too much on the value of the infrared cutoff. This short distance dominance is reflected in the large charm content of the Monte Carlo [53] and of [35] (see curves 'RS' and 'LMRT' in fig.(3), respectively). The LMRT predictions are normalised using a phenomenological fit to the '93 ZEUS data and show a significant threshold behaviour for β approaching the kinematical limit. The sharp increase for low values of β comes from the inclusion of real gluon emission (see [35]), which is not taken into account in LND.

The measurement of the charm contribution in diffraction, which should be available in the near future (at least for D^* production [57]), will certainly help our understanding of the interplay of hard and soft physics in diffraction.

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