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DIFFRACTION AT HERA: INCLUSIVE MEASUREMENTS

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Abstract

In this, the second of two reports on diffractive studies at HERA, the inclusive measurements made by the two collaborations, H1 and ZEUS, are summarized.

Event Selection

In the vector meson studies, the diffractive nature of the events is evident so that the selection of the event samples in both is quite straightforward and similar in the two experiments. For the inclusive studies, however, this is not the case. H1[1] uses their wide coverage of the forward rapidity region to select a rapidity gap to define the diffractive sample, whereas ZEUS[2] chooses to analyze the effective mass distributions measured in the central detector. Low masses are characteristic of diffraction.

The variables used to specify the events, which are illustrated in Fig. 1, are the usual ones specifying deep inelastic scattering, the two Bjorken variables (x and y), and Q^2, the negative square of the momentum transfer. The total ep cm energy is $\sqrt{s}$ (300 GeV) and $Q^2 = sxy$. In addition, two diffractive variables are used:

$$X_P = \frac{Q^2 + M_X^2}{Q^2 + W^2}, \qquad \beta = \frac{Q^2}{Q^2 + M_X^2}.$$

In the t-channel picture where a pomeron is emitted by the proton and probed by the virtual photon, X_P is the fraction of the proton momentum carried by the pomeron and β is the Bjorken x of the pomeron if it is considered as an object with a partonic structure.

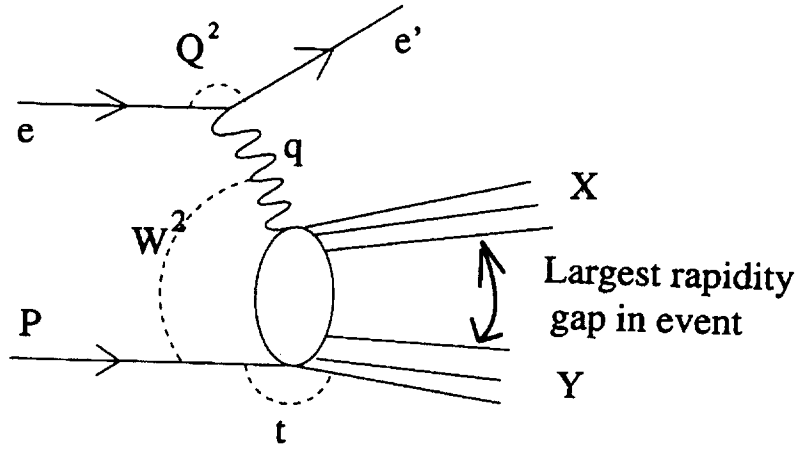


Fig. 1. Diffractive DIS event.

The kinematic regions covered in the major published studies[1,2] are similar, the main difference being that the H1 (ZEUS) events have $M_Y < 1.6(5.5)\mathrm{GeV}$.

Results Presented in the Context of the t-channel Model

a) *Inclusive Cross Sections*

If we consider the oval blob in Fig. 1 to be a color neutral pomeron, then the virtual photon probes its structure. Ignoring the longitudinal contribution, the cross section can be written as:

$$\frac{d^3\sigma}{dx d\beta dQ^2} = \frac{4\pi\alpha^2}{\beta^2 Q^4}(1+(1-y)^2)F_2^{D(3)} \;,$$

If factorization between the proton and γ^* vertices hold, then:

$$F_2^{D(3)} = F(X_p)F_2^P(\beta, Q^2),$$

where $F(X_p)$ is generically called the pomeron flux and $F_2^P(\beta, Q^2)$ is the pomeron structure function[3].

There are several parameterizations[4] for the pomeron flux term, all of which give rather similar predictions. One commonly used is:

$$F(X_P) = e^{-bt} / X_P^{2\alpha_P(t)-1} \;.$$

In this model, one would expect a peripheral t dependence at the proton vertex, similar to that measured in soft hadronic collisions. The ZEUS measurement[5], made using the Leading Proton Spectrometer (LPS), is shown in Fig. 2 supports this ideas.

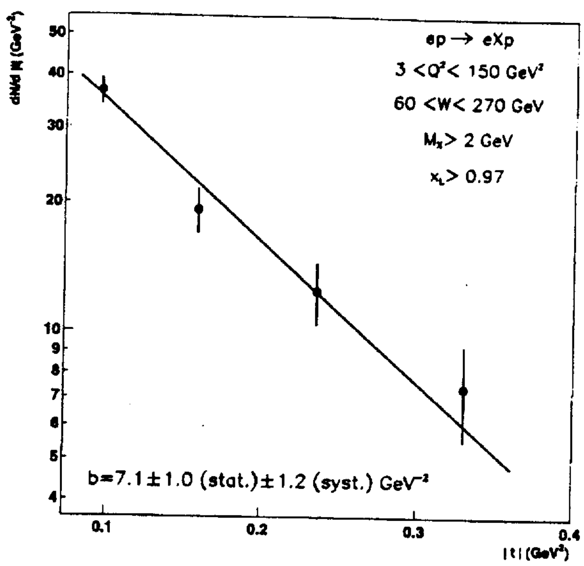


Fig. 2. t distribution of diffractive DIS.

Both the H1 and ZEUS collaborations have measured the pomeron intercept. H1 does this by making a DGLAP fit to $X_P F_2^{D(3)}$ data at fixed X_P values using both pomeron and reggion exchange terms. The result is: $\alpha_P(0) = 1.203 \pm 0.020 \pm 0.013 \pm 0.035$. The last error comes from uncertainties in the model. The ZEUS measurement is based on fitting the W dependence of $d\sigma / dM_X$ in different M_X and Q^2 bins and is shown in Fig. 3. The average of $1.157 \pm 0.009 + 0.039$ agrees well with that from H1. Both are higher than the value of about 1.1[6] obtained

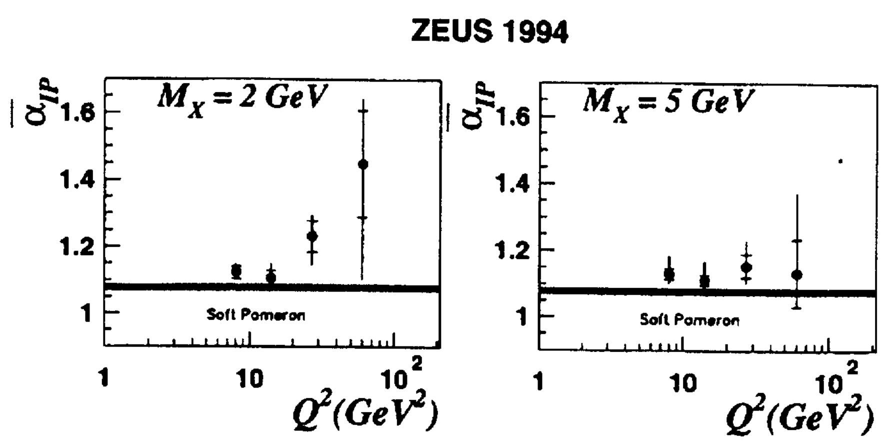


Fig. 3. Pomeron intercepts.

from hadronic data. Within the Q^2 range currently measured at HERA, there is no evidence for a Q^2 dependence of the pomeron intercept.

The values of $X_P F_2^{D(3)}$, measured by H1[1], increase with Q^2 pointing to the dominance of gluon splitting rather than quark bremmstrahlung as the origin of the scale breaking. The β distributions are rather flat. DGLAP QCD fits were made using pomeron plus reggion exchanges: two good solutions were obtained for the parton distributions in the pomeron. Both solutions are gluon dominated: one has a high β peak, the second is rather flat. As Q^2 increases, the distributions develop an excess at low β.

In a recent study[7], H1 has compared their previous fits to new high Q^2 data, as shown in Fig. 4. The importance of the reggion term at high X_P is evident. The results of the two experiments, shown in Fig. 5, do not agree perfectly which is not too surprising, considering the different techniques used to extract the diffractive cross sections and the ambiguities of defining what, in fact, constitutes the diffractive cross section. The H1 data extends to higher X_P values. The ZEUS data do not require a reggion term.

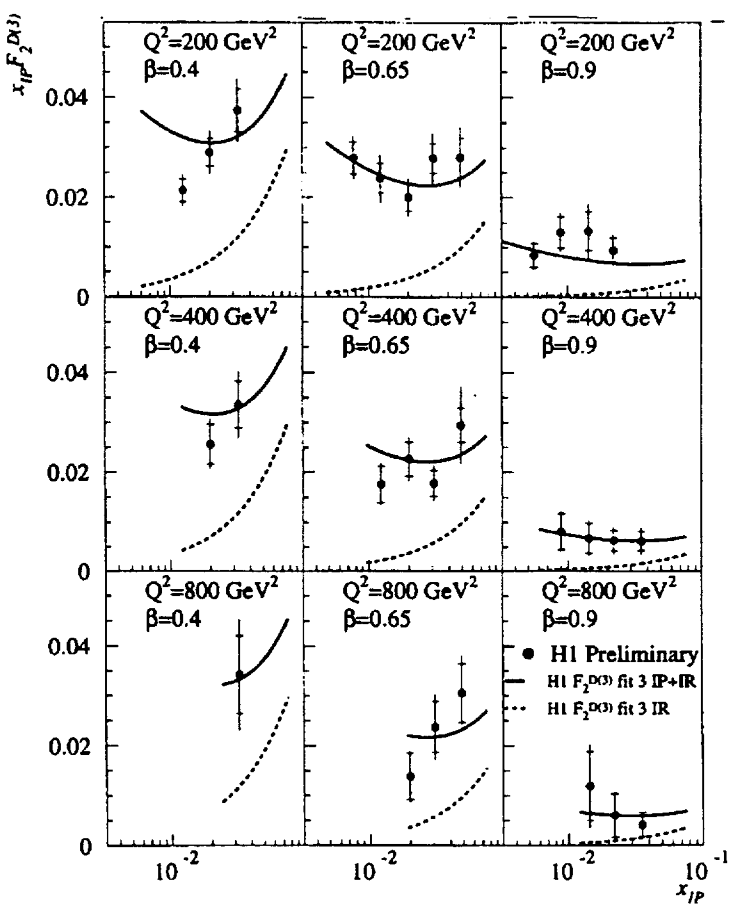


Fig. 4. High Q^2 H1 data compared to previous fit.

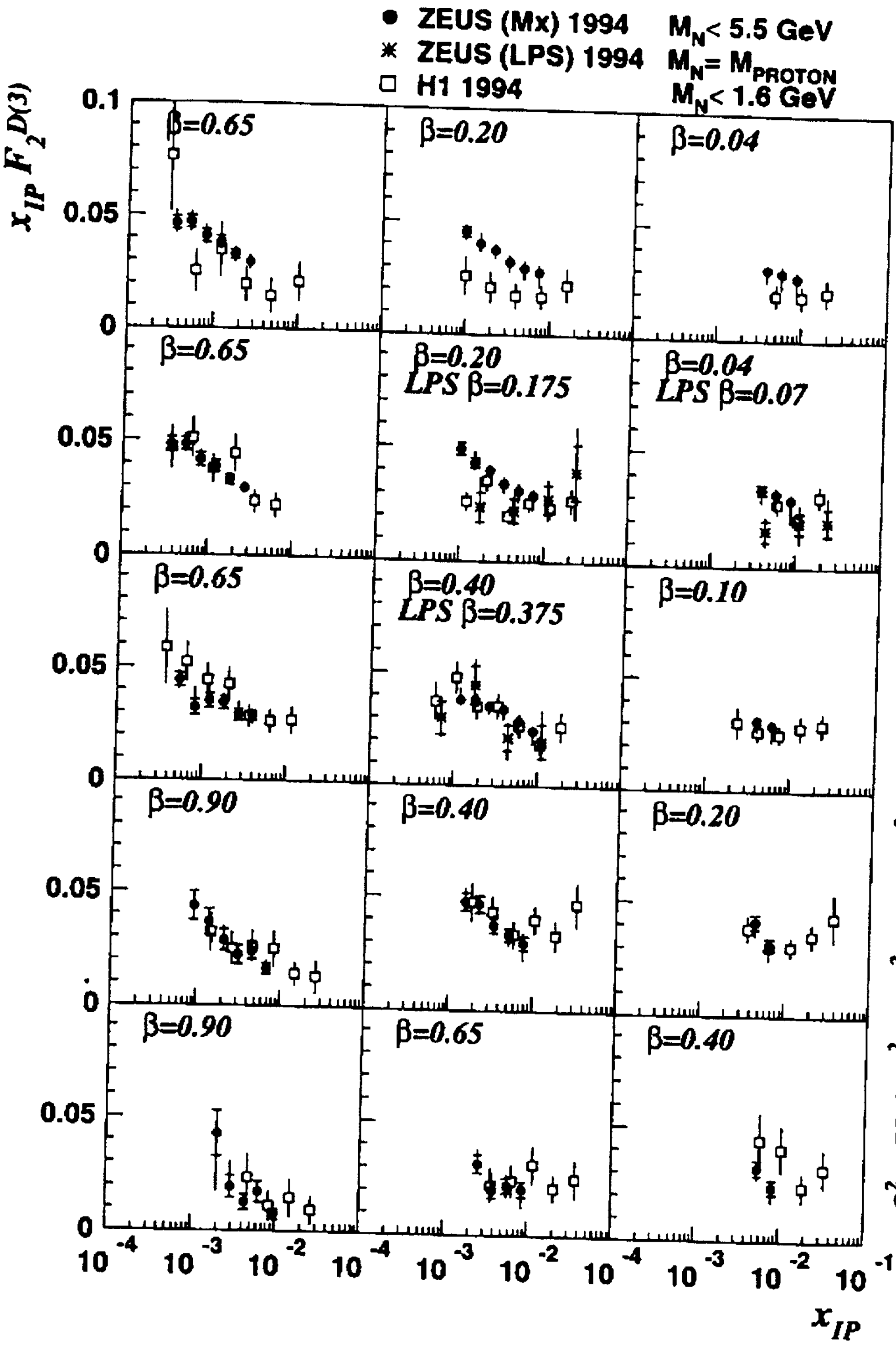


Fig. 5. Comparison of H1 and ZEUS data.

b) *Photoproduction of Dijets*

These conclusions about gluon dominance of the pomeron structure can be checked by dijet measurements in photoproduction. A gluon-dominated pomeron will yield higher cross sections than a quark dominated one. The early ZEUS measurements[8] were the first such indication. The direct and resolved photon coupling reactions are sketched in Fig. 6. The new results[9] are presented in

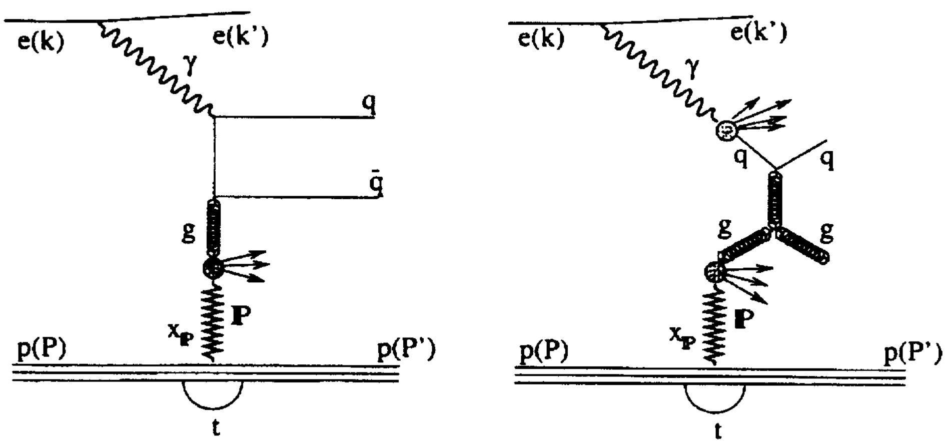
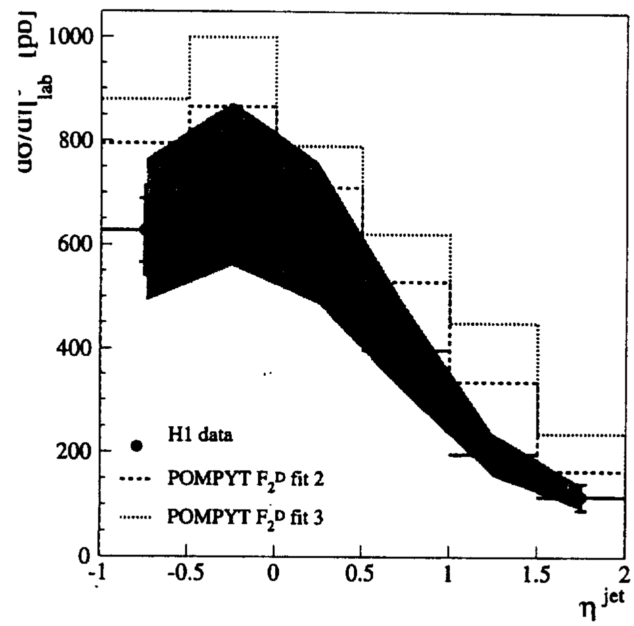


Fig. 6. Direct and resolved photoproduction of dijets.

Fig. 7. The kinematic ranges are a little different: H1, $P_t^{jet} > 5\,\mathrm{GeV}$, $-1 < \eta_{jet} < 2$, and ZEUS: $P_t^{jet} > 6\,\mathrm{GeV}$, $-1.5 < \eta_{jet} < 1$, but the conclusions agree that gluons dominate and that the flat gluon solution (fit 2) is favored over the peaked gluon solution (fit 3). The ZEUS data on x_γ, which is the fraction of the photon momentum entering the hard scattering, indicates both direct (high x_γ) and resolved contributions are present. The H1 measurements of dijets in DIS lead to the same conclusion. The gluon momentum fraction in the pomeron that results from the ZEUS analysis is in good agreement with that obtained by H1. It is by now well known that such a model fails to account for the Tevatron data[10], as will be discussed in the talk of Goulianos.



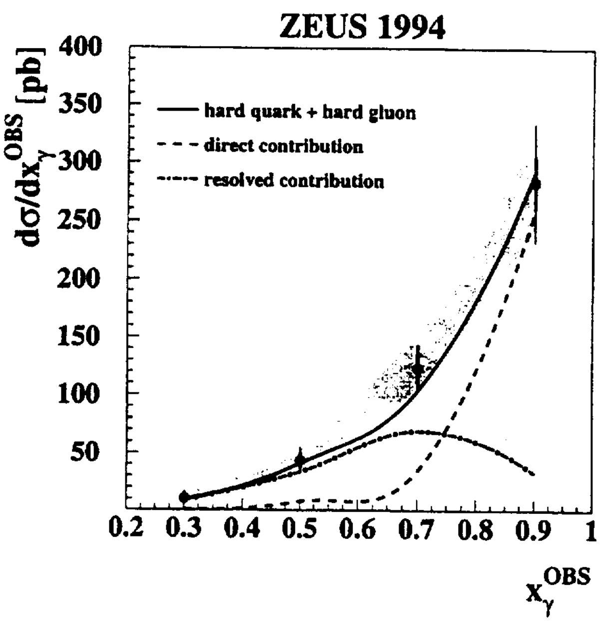


Fig. 7. H1 and ZEUS dijet measurements.

S-Channel Models

a) *Two Gluon Exchange*

In an alternative picture of DIS diffraction, the virtual photon dissociates into a $q\bar{q}$ pair which then couple to the proton via the exchange of two gluons. The soft limit of this process, when the $q\bar{q}$ pair are far apart, leads to an "aligned jet" final state[11]. In the hard limit, which corresponds to a small $q\bar{q}$ system, the cross section varies as $(xg(x))^2$. In addition to the $q\bar{q}$ system, the photon can also dissociate to $q\bar{q}g$ which leads to an effective gg dipole if the $q\bar{q}$ system is small.

In an extensive recent study[12], the following anzatz was suggested for $F_2^{D(3)}$:

$$x_P F_2^{D(3)}(\beta, x_p, Q^2) = C_T F_{q\bar{q}}^T + C_L F_{q\bar{q}}^L + C_g F_{q\bar{q}g}^T,$$

where the three terms correspond to transverse and the longitudinal $q\bar{q}$ systems of which the latter is higher twist, and the transverse $q\bar{q}g$ state. The longitudinal $q\bar{q}g$ term is neglected. The assumed functional forms for the three terms are:

Transverse term: $$F_{q\bar{q}}^T = \left(\frac{x_0}{x_p}\right)^{n_T(Q^2)} \beta(1-\beta).$$

Longitudinal term: $$F_{q\bar{q}}^L = \left(\frac{x_0}{x_p}\right)^{n_L(Q^2)} \left[\ln\left(\frac{7}{4} + \frac{Q^2}{4\beta Q_0^2}\right)\right]^2 \beta^3(1-2\beta)^2.$$

Gluon term: $$F_{q\bar{q}g}^T = \left(\frac{x_0}{x_p}\right)^{n_T(Q^2)} \ln\left(\frac{Q^2}{Q_0^2}\right)(1-\beta)^\gamma.$$

The expected value of γ is 3(2) in according to BEKW(NZ). The power indices are assumed to vary slowly with Q^2. Note that this is a non-factorizing model, although factorization may be valid approximately.

The fits of this model to the ZEUS data[2] are shown in Fig. 8, together with the expectations of two other models[13]. Similar comparisons to H1 data[14] are shown in Fig. 9. The fitted values of γ are 3.9 $\pm$0.9 for ZEUS and 8.22 $\pm$0.78 $\pm$ 0.44 for H1. The latter collaboration also finds a (poorer) solution with γ = 0.14 $\pm$0.07 $\pm$0.05. So one concludes that fits to this model do not support a leading gluon behavior.

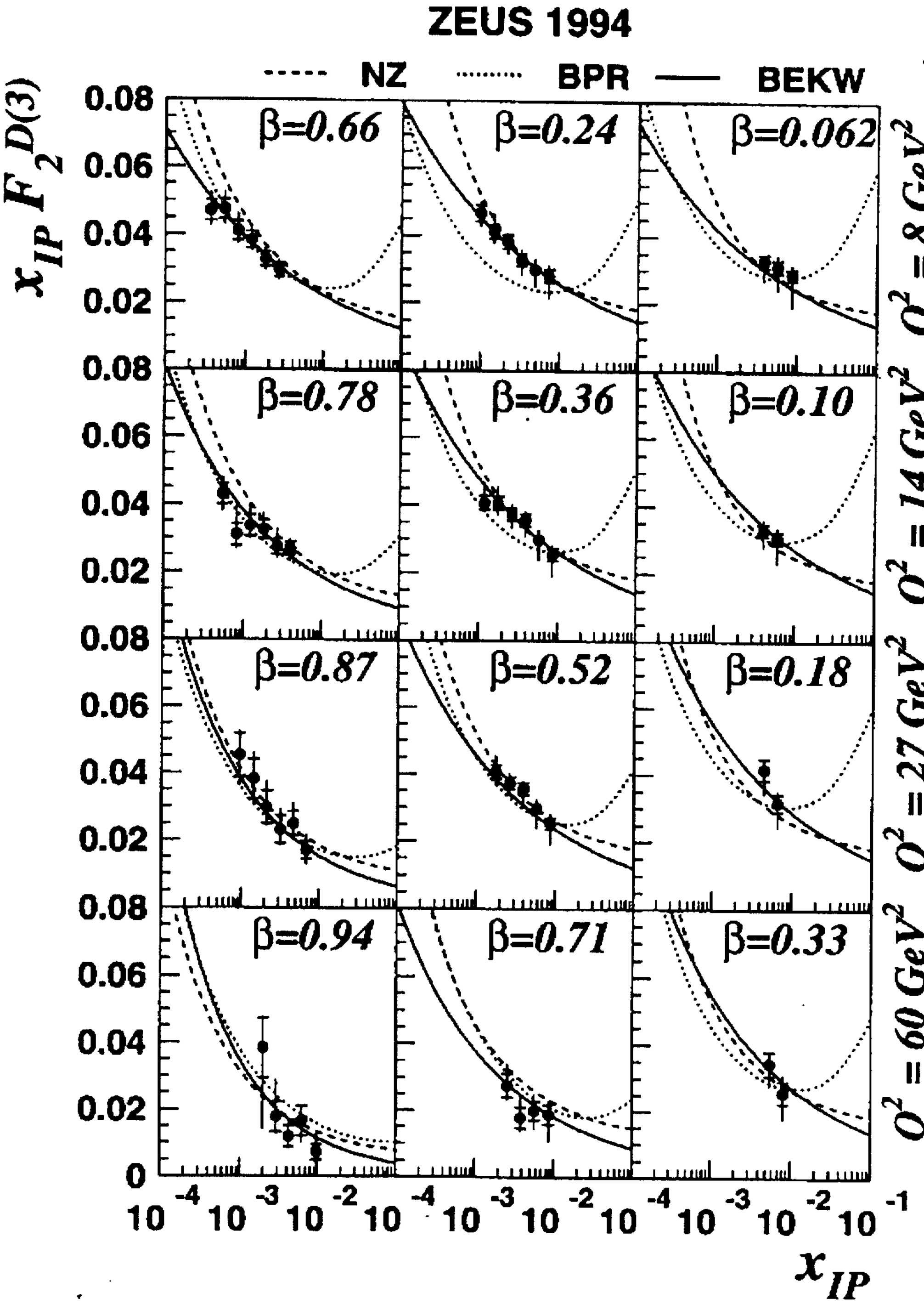


Fig. 8. ZEUS data compared to s-channel models.

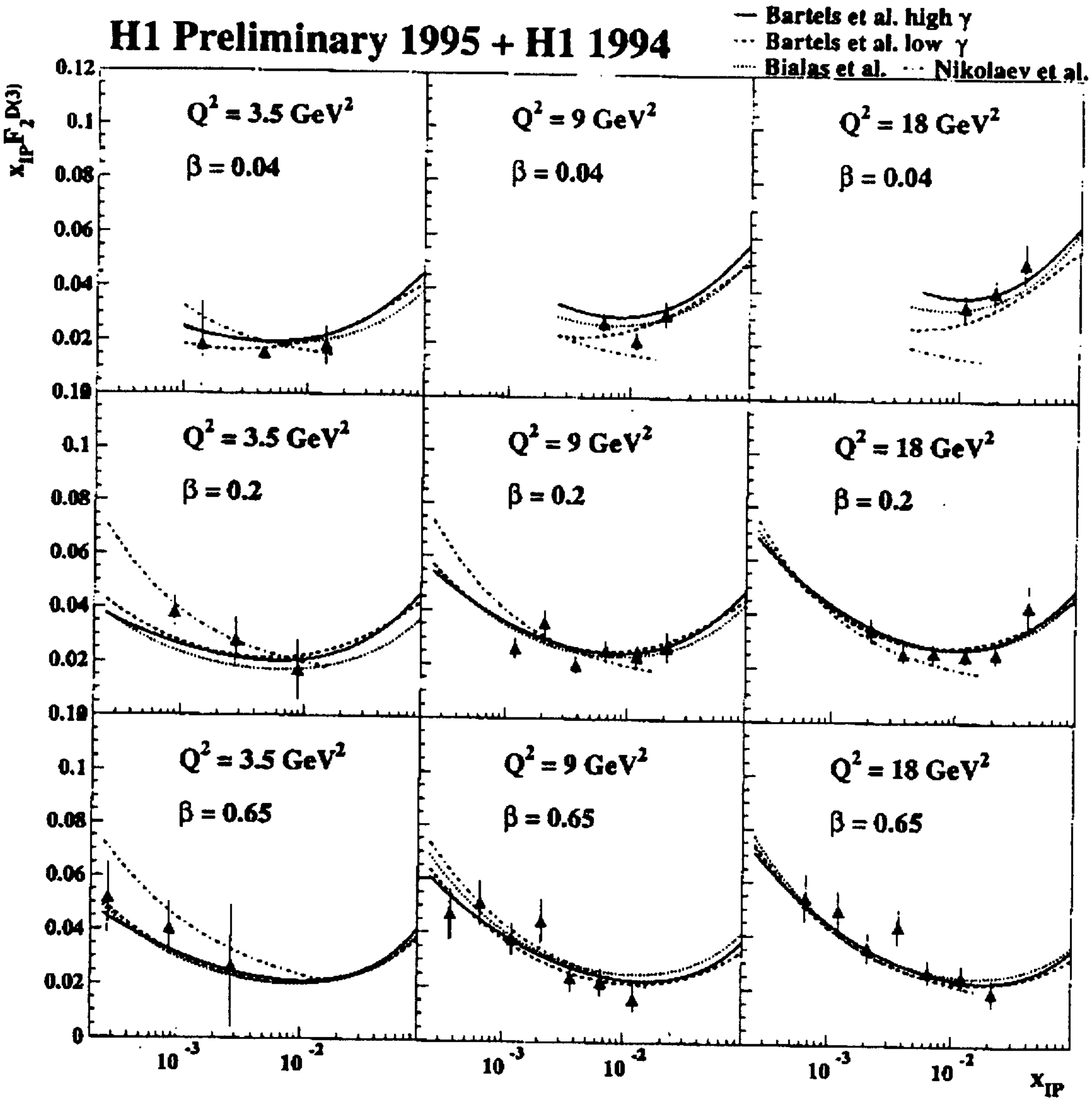


Fig. 9. H1 data compared to s-channel models.

The β dependence of the ZEUS BEKW fits is shown in Fig. 10. In this picture, the scaling violations have a different origin – the different Q^2 dependences of the transverse, the longitudinal and the gluon terms.

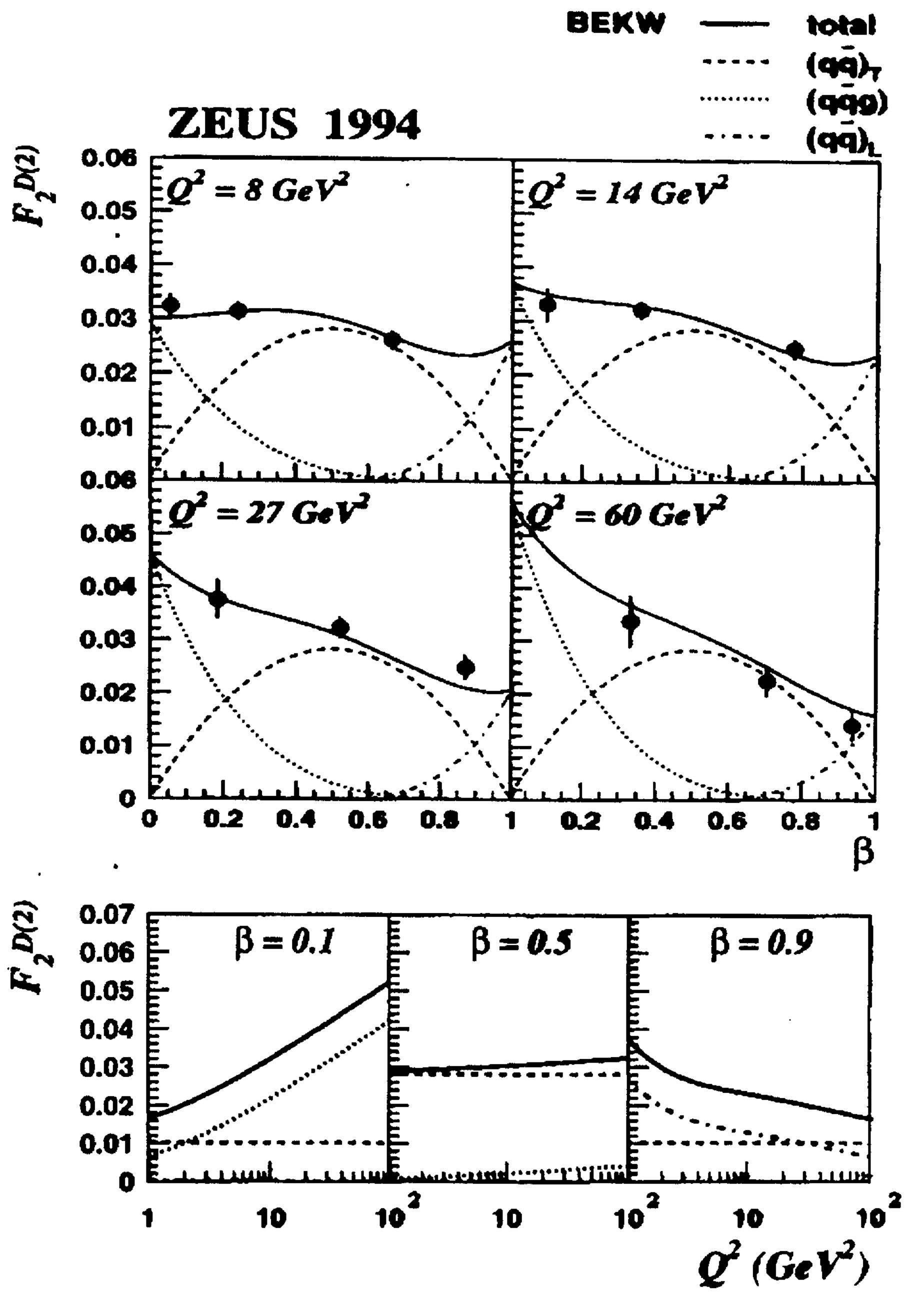


Fig. 10. β and Q^2 dependences of BEKW.

b) *Semi-classical Model*

In this picture[15], the $q\bar{q}$ pair penetrates through the proton at rest, which is a sea of gluons and suffers a color rotation, coming out as a singlet. The result is a diffractive /total cross section = 1/(1+8). This is similar to the color evaporation model of J/ψ production[16]. One therefore expects:

$$F_2^D(x, Q^2, M_X^2) = \text{const.}\, F_2(x = X_p, Q^2).$$

Buchmueller and Haidt showed[17] that $F_2(x, Q^2)$ can be fit by the double log scaling form:

$$F_2(x, Q^2) = a + m \log Q^2 / Q_0^2 \log \frac{x_0}{x}.$$

This model agrees well with the ZEUS data[2].

Diffractive Charm Production

Open charm has been measured by both collaborations[18] using the $D^{*+} \rightarrow D^{o}\pi^{+}$ decay channel. The cross sections are:

ZEUS: $379 \pm 66 + 99 - 140$ pb for 3, $Q^2 < 150$ GeV^2, $0.02 < y < 0.7$, $0.002\ x_p < 0.12$, $\beta < 0.8$, $P_t^{D*} > 1.5$ GeV, $-1.5 < \eta < 1.5$.

H1: $154 \pm 40 \pm 35$ pb for $2 < Q^2 < 100$ GeV^2, $0.05 < y < 0.7$, $x_p < 0.04$, $P_t^{D*} > 2$ GeV, $-1.5 < \eta < 1.5$.

Considering the different cuts, particularly those on P_t, these cross sections agree. ZEUS also measures a ratio of the diffractive to the total cross section of $(7 \pm 1.3 + 1.7 - 1.8)\%$.. The charm cross sections are well reproduced, within the large errors, by the Alvero et al. calculation[10], which gives 352 pb for the ZEUS cuts and by the semi-classical model[10] which gives 267 pb.

Conclusions

It is evident from this short review that the study of diffraction in DIS is a work in progress.

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