Diffractive parton densities

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We present a phenomenological model of hard diffraction in which the structure of the Pomeron is derived from the structure of the parent hadron. Predictions for diffractive deep inelastic scattering are compared with data.

The inclusive and diffractive deep inelastic scattering (DIS) cross sections are proportional to the corresponding F_2 structure functions of the proton,

$$\text{Inclusive DIS} \quad \frac{d^2\sigma}{dx dQ^2} \propto \frac{F_2^h(x,Q^2)}{x}$$

$$\text{Diffractive DIS} \quad \frac{d^3\sigma}{d\xi dx dQ^2} \propto \frac{F_2^{D(3)}(\xi,x,Q^2)}{x}$$

where h and $D(3)$ indicate, respectively, a *hard* structure function (at scale Q^2) and a 3-variable diffractive structure function (integrated over t). The latter depends not only on the hard scale Q^2, but also on the *soft* scale, $\langle M_T\rangle \sim 1$ GeV, which is the relevant scale for the formation of the gap.

The only marker of the rapidity gap is the variable ξ. We therefore postulate that the rapidity gap probability is proportional to the *soft* parton density at ξ and write the DDIS (diffractive DIS) cross section as

$$\frac{d^3\sigma}{d\xi dx dQ^2} \propto \frac{F_2^h(x,Q^2)}{x} \times \frac{F_2^s(\xi)}{\xi} \otimes \xi\text{−norm}$$

where the symbolic notation "$\otimes\ \xi$−norm" is used to indicate that the ξ probability is normalized. Since $x = \beta\xi$, the normalization over all available ξ values involves not only F_2^s but also F_2^h, breaking down factorization. It is therefore prudent to write the DDIS cross section in terms of β instead of x, so that the dependence of F_2^h on ξ is shown explicitly:

$$\frac{d^3\sigma}{d\xi d\beta dQ^2} \propto \frac{1}{\beta}\left[F_2^h(\beta\xi,Q^2) \times \frac{F_2^s(\xi)}{\xi} \otimes \xi\text{−norm}\right]$$

The term in the brackets represents the DDIS structure function $F_2^{D(3)}(\xi,\beta,Q^2)$.

In the next step, we seek guidance from the scaling behavior of the soft single-diffractive (sd) differential cross section [1,2],

$$\frac{d\sigma_{sd}}{dM^2} \propto \frac{1}{(M^2)^{1+\epsilon}} \quad \text{(no } s\text{-dependence!)}$$

which in terms of ξ takes the form

$$\frac{d\sigma_{sd}}{d\xi} \propto \underbrace{\frac{1}{s^{2\epsilon}}\,\frac{1}{\xi^{1+2\epsilon}}}_{\text{gap probability}} \times (s')^{\epsilon}$$

where $s' \equiv M^2$ is the s-value of the diffractive sub-system. Noting that ξ is related to the associated rapidity gap by $\Delta Y = \ln\frac{1}{\xi}$, and that the integral $\int_{(s_o/s)}^{1} \frac{1}{s^{2\epsilon}}\,\frac{d\xi}{\xi^{1+2\epsilon}} = constant$, the above equation may be viewed as representing the product of the total cross section at the sub-system energy multiplied by a *normalized* rapidity gap probability. In analogy with this experimentally established behavior, we factorize $F_2^{D(3)}(\xi,\beta,Q^2)$ into $F_2^h(\beta,Q^2)$, the sub-energy DIS cross section, times a normalized gap probability:

$$F_2^{D(3)}(\xi,\beta,Q^2) = P_{gap}(\xi,\beta,Q^2) \times F_2^h(\beta,Q^2)$$

The gap probability is therefore given by

$$P_{gap}(\xi,\beta,Q^2) = F_2^h(\beta\xi,Q^2) \times \frac{F_2^s(\xi)}{\xi} \times N(s,\beta,Q^2)$$

The normalization factor, $N(s,\beta,Q^2)$, is obtained from the following equation, using $\xi_{min} = Q^2/s$,

$$N^{-1}(s,\beta,Q^2) = \frac{1}{f_q}\int_{\xi_{min}}^{1} F_2^h(\beta\xi,Q^2) \times \frac{F_2^s(\xi)}{\xi} d\xi$$

f_q is the quark fraction of the hard structure and is used here because only quarks participate in DIS.

At small x ($\leq\sim 0.1$), the structure functions F_2^h and F_2^s are represented well by the power law expressions [3] $F_2^h(x,Q^2) = A^h/x^{\lambda_h(Q^2)}$ and $F_2^s(\xi) = A^s/\xi^{\lambda_s}$. Using these forms we obtain

$$N^{-1}(s,\beta,Q^2) = \frac{1}{f_q}\left[\frac{A^h}{\beta^{\lambda_h}}\,\frac{A^s}{\lambda_h+\lambda_s}\,\left(\frac{\beta s}{Q^2}\right)^{\lambda_h+\lambda_s}\right]$$

$$F_2^{D(3)}(\xi,\beta,Q^2) =$$
$$\frac{1}{\xi^{1+\lambda_h+\lambda_s}} \times f_q(\lambda_h+\lambda_s)\ \left(\frac{Q^2}{\beta s}\right)^{\lambda_h+\lambda_s} \times \frac{A^h}{\beta^{\lambda_h}}$$

Since in DDIS x is always smaller than ξ, the above form of $F_2^{D(3)}$, derived for small x, should be valid for all x when ξ is small; it should also be valid for all $\beta(=x/\xi)$. We therefore expect $F_2^{D(3)}$ to have the following ξ and β dependence at small ξ:

$$F_2^{D(3)}(\xi,\beta,Q^2)|_{\beta,Q^2} \propto \frac{1}{\xi^{1+n}} \qquad n = \lambda_h(Q^2) + \lambda_s$$

$$F_2^{D(3)}(\xi,\beta,Q^2)|_{\xi,Q^2} \propto \frac{1}{\beta^m} \qquad m = 2\lambda_h(Q^2) + \lambda_s$$

The HERA (non-diffractive) DIS measurements [3] yield $\lambda_s \approx 0.1$, which is in agreement with the value of $\epsilon = \alpha(0) - 1 = 0.104$ [4], where $\alpha(0)$ is the intercept of the Pomeron trajectory at t=0. In the Q^2 range of 10-50 GeV^2, where the DDIS data are concentrated, these measurements yield $\lambda_h \approx 0.3$. Using these values we obtain $n = 0.4$ and $m = 0.7$. We therefore expect

$$\text{Prediction:} \quad F_2^{D(3)} \propto \frac{1}{\xi^{1.4}} \times \frac{1}{\beta^{0.7}}$$

We observe the following features:

Factorization

Our prediction exhibits factorization between ξ and β, in agreement with HERA results at small ξ.

ξ-dependence

In the Regge framework, the ξ-dependence of $F_2^{D(3)}$ is expected to have the "Pomeron flux" form $\sim 1/\xi^{1+n}$ with $n = 2\epsilon = 0.2$, independent of Q^2. In the Q^2 range of 10-50 GeV^2, the HERA experiments find that n is ≈ 0.4 and has a small Q^2 dependence, in agreement with our prediction of $n = \lambda_h(Q^2) + \lambda_s$.

β-dependence

The predicted form $1/\beta^m$ for $F_2^{D(3)}$ is valid in the region of (fixed) small ξ and high Q^2, where the x-distribution of $F_2(x,Q^2)$ has the form $A^h/x^{\lambda_h(Q^2)}$. As there are no data points at strictly fixed ξ, we have selected the following set of five points at $Q^2 = 45$ GeV^2 and $\xi \approx 0.01$ from Ref. [5] with which to compare the measured values of $F_2^{D(3)}$ with our prediction:

β	x	$\xi = x/\beta$	$\xi \cdot F_2^{D(3)} \pm stat \pm syst$
0.10	0.00133	0.0133	$0.0384 \pm 0.0066 \pm 0.0030$
0.20	0.00237	0.0118	$0.0406 \pm 0.0061 \pm 0.0026$
0.40	0.00421	0.0105	$0.0215 \pm 0.0046 \pm 0.0016$
0.65	0.00750	0.0115	$0.0240 \pm 0.0054 \pm 0.0026$
0.90	0.00750	0.0083	$0.0088 \pm 0.0041 \pm 0.0005$

The following parameters are used in the calculation of $F_2^{D(3)}$: $\sqrt{s} = 280$ GeV, $\xi = 0.01$, $Q^2 = 45$ GeV^2, $\lambda_s = 0.1$, $\lambda_h = 0.3$, $f_q = 0.4$ [7], and $A^h = 0.2$; the latter was evaluated from $F_2(Q^2 = 50, x = 0.00133) = 1.46$ [6] assuming a $\frac{A^h}{x^{0.3}}$ dependence. In figure 1, our prediction for $\xi \cdot F_2^{D(3)}(\beta)$ versus β is compared with the data. The observed agreement both in shape and normalization is satisfactory, particularly since no free parameters are used in the calculation.

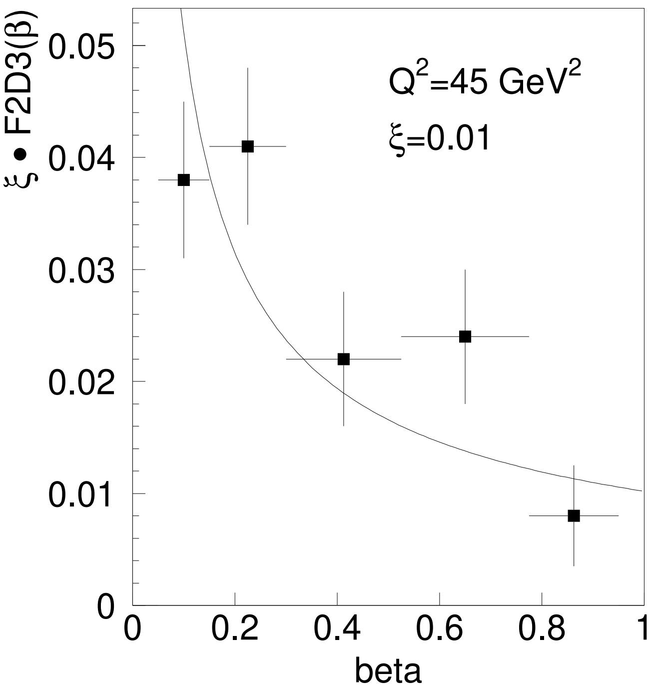

Figure 1. Predicted β dependence of $\xi \times F_2^{D(3)}(\xi,\beta,Q^2)$ for $\xi = 0.01$ and $Q^2 = 45$ GeV^2 (solid curve) compared with measured values (points) obtained from Ref. [5]

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