A NEW APPROACH TO DIFFRACTION

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A new phenomenological approach to hard diffraction is presented, in which the diffractive structure function of the proton is assumed to be the appropriately normalized product of the non-diffractive structure function at the hard scale and the soft non-diffractive parton density evaluated at an x-value corresponding to the edge of the rapidity gap. Explicit predictions of the model for large-gap diffractive deep inelastic scattering are compared with features observed in HERA 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 $\xi = x_{I\!P}$ is the fractional momentum loss of the proton and the superscripts 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, $\langle p_T \rangle \sim 1$ GeV, which is the relevant scale for the formation of the diffractive rapidity gap.

The only marker of the rapidity gap $\Delta\eta \approx \ln\frac{1}{\xi}$ 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

$$\frac{d^3\sigma}{d\xi dx dQ^2} \propto \frac{F_2^h(x,Q^2)}{x} \times \frac{F^s(\xi)}{\xi} \times N(\beta, Q^2, \xi_{min})$$

where $F^s(\xi)/\xi$ is the parton density at the soft scale and $N(\beta, Q^2, \xi_{min})$ is a normalization factor introduced to guarantee that the rapidity gap probability at fixed $\beta \equiv x/\xi$ integrated over all available ξ-space, and therefore depending on $\xi_{min} = \frac{x_{min}}{\beta} = \frac{Q^2}{\beta s}$, saturates at unity. This saturation, which prevents unitarity from being violated due to the rapid rise of the structure function with decreasing x, is similar to the saturation caused by the "screening corrections" applicable to the low Q^2 region. The dependence of $N(\beta, Q^2, \xi_{min})$ on $\xi_{min} = Q^2/\beta s$ results in a breakdown of factorization. At high Q^2, where the gap probability is not saturated, factorization should hold[1].

Motivated by the scaling behavior observed in the $d\sigma/dM^2$ distribution of the single diffractive (SD) cross section[1,2], we change variables $x \to \beta\xi$ and write $F_2^{D(3)}(\xi, \beta, Q^2, \xi_{min})$ as the product of the sub-energy DIS cross section, $F_2^h(\beta, Q^2)$, times a normalized (over all ξ) gap probability:

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

The factor f_c is a "color singlet factor" introduced to account for the fact that the combination of a hard plus a soft exchange must be a color singlet. In DDIS f_c is taken to be equal to $\frac{1}{2}$, since the removal of a quark from the proton on the hard scale must be matched by the removal of an antiquark on the soft scale, limiting the number of (anti)quarks available for the formation of a color singlet to $\frac{1}{2}$ of the total number.

The normalized gap probability is given by

$$P_{gap}(\xi, \beta, Q^2, \xi_{min}) = \frac{F_2^h(\beta\xi, Q^2) \times \frac{F^s(\xi)}{\xi}}{\displaystyle\int_{\xi_{min}}^{1} F_2^h(\beta\xi, Q^2) \times \frac{F^s(\xi)}{\xi} d\xi}$$

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

$$F_2^{D(3)}(\xi, \beta, Q^2, \xi_{min}) = \frac{1}{\xi^{1+\lambda_h+\lambda_s}} \times (\lambda_h + \lambda_s) \left(\frac{Q^2}{\beta s}\right)^{\lambda_h+\lambda_s} \times \left[f_c \times \frac{A^h}{\beta^{\lambda_h}}\right] \quad (1)$$

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 β, since $\beta = x/\xi$. We therefore expect $F_2^{D(3)}$ to have the following ξ and β dependence at small ξ:

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

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

The HERA (non-diffractive) DIS measurements[3] yield $\lambda_h(Q^2) \approx 0.1 + 0.053 \ln Q^2$. At $Q^2 = 1$ GeV^2, $\lambda_h \to \lambda_s \approx 0.1$, 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

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

The above equation exhibits "Regge factorization" between ξ and β, with a ξ-dependence of the (Pomeron flux) form $1/\xi^{1+n}$ but with $n = 0.4$ instead of the expectation $n = 2\epsilon = 0.2$ from soft SD and a $1/\beta^m$-dependence. These features are in agreement with HERA data[5].

Equation (1) was derived under the assumption that the rapidity gap probability is saturated and therefore must be normalized to unity. This normalization introduces the factor $(Q^2/\beta s)^n$, which overtly breaks down factorization. Factorization at high Q^2 may be preserved by replacing $(Q^2/\beta s)^n$ in Eq. (1) by the factor $C \times \left(1 - e^{-\frac{1}{C}(Q^2/\beta s)^n}\right)$, in which the constant $C = \xi_0$, to be determined experimentally, is the value of $\xi_{min} = Q^2/\beta s$ above which the gap probability integrates out to less than unity and therefore should not be renormalized. With this modification, the $F_2^{D(3)}$ becomes

$$F_2^{D(3)}(\xi, \beta, Q^2, Q^2/\beta s) = \frac{C}{\xi^{1+\lambda_h+\lambda_s}} \times (\lambda_h + \lambda_s) \left(1 - e^{-\frac{1}{C}(Q^2/\beta s)^n}\right) \times \left[f_c \times \frac{A^h}{\beta^{\lambda_h}}\right]$$

For small $Q^2/\beta s$ the above equation reverts to Eq. (1), which violates QCD factorization, while for large Q^2, $F_2^{D(3)}$ obeys both Regge and QCD factorization.

References

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