Diffractive parton distributions for a small size hadron

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We describe diffractive deeply inelastic scattering in terms of diffractive parton distributions and discuss what one can learn from the calculation of the diffractive parton distributions in hadronic systems with small transverse size.

Consider $e+p \to e+p+X$ with Q^2 large in the case in which the proton is diffractively scattered, so that it is scattered with a loss of a fraction $x_{I\!P}$ of its longitudinal momentum and an invariant momentum transfer t. The measurement can be described using the diffractive structure function $dF_2^{\rm diff}(x,Q^2;x_{I\!P},t)/[dx_{I\!P}\,dt]$, which is often called $F_2^{D(4)}$. In the theoretical analysis of this quantity, the property of *diffractive factorization* is very useful. This property is analogous to the factorization property of the inclusive structure function F_2:

$$F_2(x,Q^2) \sim \sum_a \int_0^1 d\xi\ f_{a/A}(\xi,\mu)\ \widehat{F}_{2,a}(x/\xi,Q^2;\mu), \qquad (1)$$

with corrections suppressed by a power of Q. Here $\widehat{F}_2$ is calculable in perturbation theory. According to diffractive factorization, the diffractive F_2 takes the form[1–3],

$$\frac{dF_2^{\rm diff}(x,Q^2;x_{I\!P},t)}{dx_{I\!P}\,dt} \sim \sum_a \int_0^{x_{I\!P}} d\xi \frac{d\,f_{a/A}^{\rm diff}(\xi,\mu;x_{I\!P},t)}{dx_{I\!P}\,dt}\ \widehat{F}_{2,a}(x/\xi,Q^2;\mu). \qquad (2)$$

Here $\widehat{F}_2$ is the same function as in the inclusive factorization. Again, corrections are suppressed by a power of Q. The functions $d\,f_{a/A}^{\rm diff}/dx_{I\!P}\,dt$ are *diffractive parton distribution functions* and are interpreted as the probability to find a parton in the hadron on the condition that the hadron is diffractively scattered. That diffractive factorization holds for diffractive deeply inelastic scattering has been established by Collins[4]. It should be noted that the analogous property does not hold in hard scattering processes with two hadrons in the initial state[1,5].

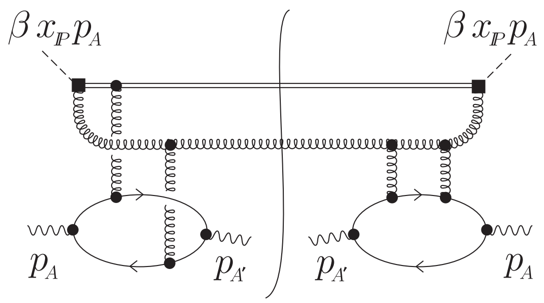

Figure 1. A graph giving a leading contribution to the diffractive gluon distribution

Starting with diffractive factorization, one can

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add the hypothesis of *Regge factorization*,

$$\frac{d\, f_{a/A}^{\rm diff}(\xi,\mu;x_{I\!P},t)}{dx_{I\!P}\,dt} = \frac{1}{8\pi^2}\,|\beta_A(t)|^2 x_{I\!P}^{-2\alpha(t)}\, f_{a/I\!P}(\xi/x_{I\!P},t,\mu)\,. \qquad (3)$$

Here $\beta_A(t)$ is the coupling of hadron A to the pomeron and $\alpha(t)$ is the pomeron trajectory ($\alpha(t) \approx 1$). Then $f_{a/I\!P}(\beta,t,\mu)$ is the distribution of partons "in" the pomeron. If one inserts Eq. (3) into Eq. (2) one has the model of Ingelman and Schlein[6].

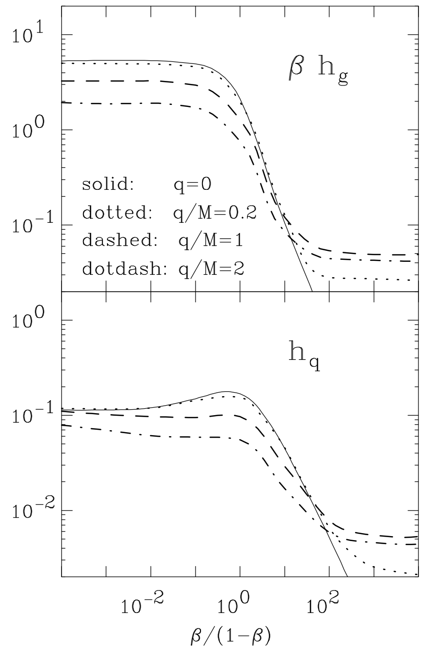

Figure 2. Diffractive gluon (top) and quark (bottom) distributions. Here h is the diffractive parton distribution multiplied by a normalization factor $x_{I\!P}^2\, M^2\,/[\alpha^2\, e_Q^4\, \alpha_s^4]$. The results are plotted versus $\beta/(1-\beta)$ for several values of $\mathbf{q}^2 \approx -t$.

The diffractive parton distribution functions have precise definitions as matrix elements of quark and gluon operators[2]. They depend on a renormalization scale μ according to the usual perturbative evolution equation.

In principle, the definitions would allow one to calculate the diffractive parton distributions. However, the fact that hadrons have a large size means that the momentum scales are small and perturbation theory is not useful. On the other hand, one could use a perturbative calculation in the case of a small hadron. We have undertaken such a calculation[7]. Our small hadron is a state consisting of a quark and an antiquark with a large mass M. The state is created by a color singlet current that we take to couple only to the large mass quarks. The lowest order contributions that can contribute to the leading behavior as $x_{I\!P} \to 0$ of the diffractive gluon distribution are from the graph shown in Fig. 1 and similar graphs.

The result[7] for the diffractive quark and gluon distributions is quite simple, but we do not repeat it here. The result is given in terms of an integral over transverse momenta in the loops and over two momentum fraction variables. The integral cannot be done analytically, but it is easy enough to do it numerically. The result is shown in Fig. 2. The most important feature is that the diffractive gluon distribution is a lot larger than the diffractive quark distribution.

The integrals in our calculation are all ultraviolet finite, so that the result has no dependence on the renormalization scale μ. At one higher order of perturbation theory, one will get contributions proportional to $\log(\mu^2/M^2)$, where M is the heavy quark mass. These terms are suppressed by an extra power of α_s so they are not important unless $\log(\mu^2/M^2)$ is large. In the case that $\log(\mu^2/M^2)$ is large we can account for these terms by applying the usual DGLAP evolution equation with the result of Fig. 2 as a boundary condition at $\mu = M$.

These results are for a small hadron. We now ask what happens in the realistic case of a big hadron. What if we made the hadron bigger and bigger until its size was 1 fm? Perhaps the soft region would start to dominate and change the result a lot. Or else, perhaps, nonperturbative physics would set in that reduces the sensitivity to the soft region and leaves a result that is close to that for a moderately small hadron. We try out this idea by setting $M = 1.5$ GeV and using the

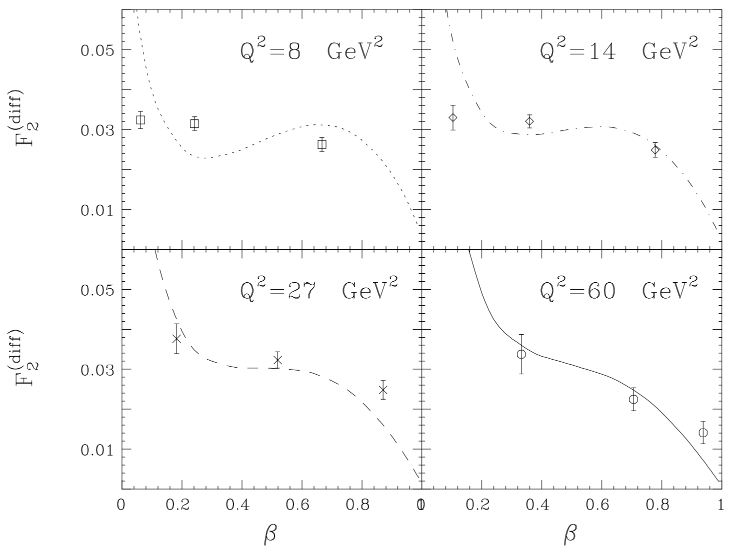

Figure 3. Results for F_2^{diff} compared with ZEUS data[8]. The normalization here is arbitrary.

two loop evolution equation to get the diffractive parton distributions in the range $\mu^2 > M^2$. Then we can use the standard order α_s hard scattering function $\widehat{F}_2$ to calculate F_2^{diff} according to Eq. (2). The result is shown in Fig. 3 compared to data from ZEUS.

The agreement between theory and experiment in Fig. 3 is evidently not perfect. However, certain qualitative features of the data are reproduced. We note that F_2^{diff} is rather flat as a function of β and, in the range of Q^2 shown, depends rather weakly on Q^2. These results are dramatically at variance with what happens in the case of the inclusive F_2 (with the correspondence $\beta \to x$). One can understand this behavior qualitatively based on the "small hadron" calculation. First, the pomeron in this picture corresponds to gluon exchange and the nature of the coupling of gluons to fast moving quarks or gluons is such that the β dependence is rather mild. Second, the diffractive gluon distribution is much larger than the diffractive quark distribution because gluons in the pomeron have a stronger coupling to gluons than they do to quarks. Thus the depletion of quarks in the mid range of β under evolution, due to gluon bremsstrahlung, is compensated by the replenishment of quarks from gluon splitting into quark-antiquark pairs.

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