Diffractive Parton Distributions

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We explore some of the consequences of our earlier determination of diffractive parton densities which are normalized to HERA data and assume hard scattering factorization. Comparisons with preliminary data from HERA and the Tevatron suggest that at low x and low Q^2, the proton's diffractive and inclusive gluon and quark distribution functions have the same x dependence.

1. INTRODUCTION

In a previous paper [1], we obtained diffractive parton densities extracted from diffractive deep inelastic scattering (DIS) and photoproduction data from HERA and then used these to predict diffractive production of W's and dijets at the Tevatron. In a second paper [2], we extended these predictions to diffractive heavy quark production in both DIS at HERA and in $\bar{p}p$ collisions at the Tevatron as well as to dijet production in double pomeron exchange at the Tevatron.

The motivation for such a picture is the notion of hard scattering factorization (HSF). The formal statement of HSF is that a reaction cross section can be written as a convolution of a hard scattering perturbative calculation and a soft, nonperturbative parton distribution. Recently, a factorization theorem has been proven [3] for "diffractive" DIS processes, where the "diffractive" condition simply means an inclusive single particle in the fragmentation region of the proton, ie neutron, proton, π, etc. The proof establishes the universality of the "diffractive" pdfs for the processes to which the theorem applies. This means that one may extract the pdfs from some DIS data, for example, and then reliably predict other diffractive DIS (DDIS) cross sections.

Note that this theorem does not apply for hadron-hadron scattering. In fact, there is no factorization theorem for diffractive hadron-hadron processes. On the contrary, arguments have been made in favor of nonfactorization. The results of [1,2] are consistent with these principles.

The calculations [1,2] were made assuming hard scattering factorization and that diffraction takes place by the exchange of a pomeron. Partons from the pomeron undergo hard scattering with a virtual photon (as in DDIS) or other partons from the other incoming hadron. Note that we use the term "parton densities in the pomeron" interchangeably with "diffractive parton densities in the proton". Our use of the former mainly provides us with a concise way to describe the type of parameterization of the diffractive parton densities that we use and the quantum numbers that we believe to be exchanged in diffraction. Technically, the latter terminology is more appropriate for the purposes of this paper as it arises directly from the factorization theorem [3].

2. SUMMARY OF FITS TO DIFFRACTIVE DATA

In this study, we will use the diffractive parton densities which we obtained [1] from fits to diffractive DIS and photoproduction data from ZEUS and H1. In the HSF formalism (eg for $\overline{p}p$):

$$\sigma^{\rm diff} = \sum_{a,b} f_{a/p}(x_a) \otimes f_{b/\mathcal{P}}(x_b) \otimes f_{\mathcal{P}/\bar{p}}(x_{\mathcal{P}}) \otimes \hat{\sigma}_{ab} \quad (1)$$

where x_a and $x_{\mathcal{P}}$ are the momentum fractions of parton a and the pomeron, respectively; $f_{a/p}(x_a)$ is the distribution function of parton a in the proton, CTEQ4M [4]; and $f_{b/\mathcal{P}}(x_b = \beta)$ is the distribution function of parton b in the pomeron. Five different hypotheses for this distribution were tried: the fits are labeled A, B, C, D and SG.

Parameterizations A-D have the form, at an initial scale $Q_0 = 2$ GeV,

$$\begin{aligned} \beta f_{q/\mathcal{P}}(\beta) &= a_q \left[\beta(1-\beta) + \tilde{a}_q (1-\beta)^2\right], \\ \beta f_{g/\mathcal{P}}(\beta) &= a_g \beta(1-\beta). \end{aligned} \tag{2}$$

The "super-high glue" fit, SG, has the same form of quark density as in Eq. (2) but with a gluon density that is peaked near $\beta = 1$ and given by

$$\beta f_{g/\mathcal{P}}(\beta) = a_g \beta^8 (1-\beta)^{0.3}. \tag{3}$$

a_q, $\tilde{a}_q$ and a_g are parameters determined in the fits. In Fits A and C, a_g was set to 0; in Fits A, B and SG, $\tilde{a}_q$ was set to 0. $f_{\mathcal{P}/\bar{p}}$ is the 'flux of pomerons in the (anti)proton'. The flux factor used with the above parton densities was the Donnachie-Landshoff flux [5] with a pomeron trajectory $\alpha(t) = \alpha(0) + 0.25t$ ($\alpha(0)$ is a fit parameter determined to be 1.14), $x_{\mathcal{P}}$ is x/β and $\hat{\sigma}_{ab}$ is the partonic hard scattering coefficient. Note that fits A and C have low gluon content (i.e., gluons are only produced via evolution) while fits B, D and SG contain large amounts of initial gluons.

To summarize the relevant results of [1], only the high glue fits are able to fit the jet photoproduction data while the low glue fits badly underestimate the same data. All five parameterizations are in reasonable agreement with the inclusive diffractive DIS data.

3. SUMMARY OF RESULTS

Our results [1,2] for diffractive dijet and W production at the Tevatron suggested a breakdown of HSF for diffractive hadron-induced processes. The predicted double pomeron exchange (DPE) cross sections with the high glue fits are factors of 10-100 times larger than data. Only the low glue fits, which do not fit the diffractive photoproduction data, yield numbers that agree well with the data.

Since open charm production is dominated by the photon-gluon fusion process, it also provides a good test of the normalization of the diffractive gluon density. In [2] we computed the cross section for DDIS production of heavy quarks with HVQDISv1.1 [6] which computes differential heavy quark distributions in DIS to next-to-leading order (NLO). We modified this calculation to use the diffractive parton densities determined in [1].

The ZEUS collaboration has reported preliminary data [7] on charm production in DDIS from the process

$$e^+ + p \to e^+ + p + D^{*\pm} + X. \tag{4}$$

Our predictions, using pomeron densities with a large amount of initial gluon, for diffractive D^* production at HERA agree well with the data. In particular, fit D, which has the best overall fit to the DIS and jet photoproduction data, also has the best agreement with the D^* data. The predictions obtained with the low glue fits A and C are one to two orders of magnitude smaller than the data. This supports the notion of hard scattering factorization for diffractive DIS processes.

4. DIFFRACTIVE PARTON DISTRIBUTIONS

In Eq. (1), we can combine two of the terms:

$$f_{b/\bar{p}}^{diff}(x_b/x_{\mathcal{P}}, x_{\mathcal{P}}, t) = f_{b/\mathcal{P}}(x_b) \otimes f_{\mathcal{P}/\bar{p}}(x_{\mathcal{P}}) \tag{5}$$

yielding

$$\sigma^{\rm diff} = \sum_{a,b} f_{a/p}(x_a) \otimes f_{b/\bar{p}}^{diff}(x_b/x_{\mathcal{P}}, x_{\mathcal{P}}, t) \otimes \hat{\sigma}_{ab} \tag{6}$$

in which a diffractive parton distribution function, $f_{b/\bar{p}}^{diff}$, can then be defined as:

$$f_{b/p}^{diff}(x, Q^2) = \int_{\beta^{min}}^{1} \frac{d\beta}{\beta} f_{b/\mathcal{P}}(\beta, Q^2) f_{\mathcal{P}/p}^{DL}(x/\beta) \tag{7}$$

where the lower limit of integration corresponds to our definition of diffraction, i.e., $x_L = (1 - x_{\mathcal{P}}) > 0.99$ or $\beta^{min} = x/0.01$. We can then compare this distribution to the *inclusive* proton parton distribution functions for the gluon and for the sum of the light quarks ($u + \bar{u} + d + \bar{d}$): $f_{a/p}(x_a, Q^2)$. We now consider only Fit D.

Figure 1 shows the results of the integration with $\beta^{min} = x/0.01$. We observe that at low Q^2 and low x the diffractive and inclusive pdfs have essentially the same x dependence.

Figure 2 shows the ratio of the diffractive parton density to the inclusive proton density. We note that at low Q^2 the two densities have a very

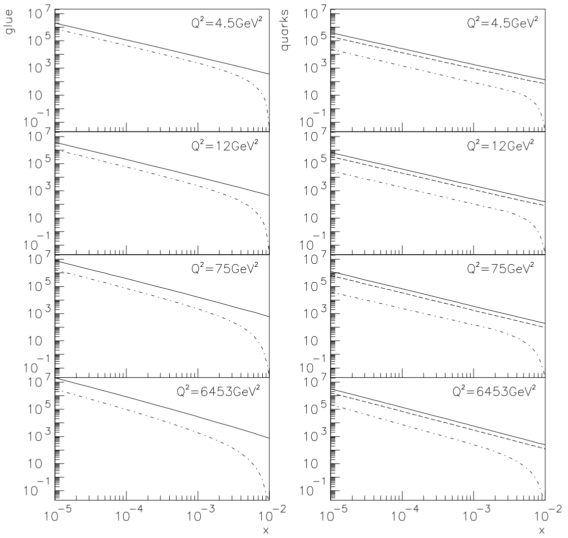

Figure 1. The diffractive and inclusive proton parton distributions as a function of x at four different values of Q^2. The left-hand plots show the gluon distributions while the right-hand plots show the sum of the $(u+\bar{u}+d+\bar{d})$ quark distributions. The solid curves are the inclusive distributions obtained by CTEQ4M while the predictions obtained from fit D are shown as the dot-dashed curves.

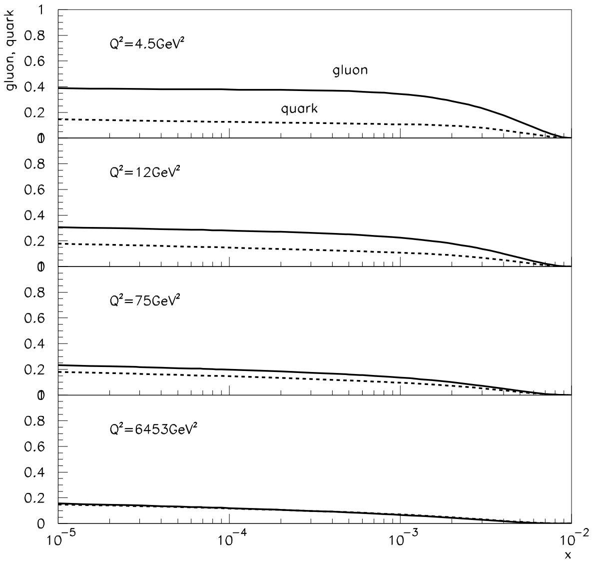

Figure 2. The ratio of the diffractive and inclusive proton parton distributions as a function of x at four different values of Q^2. The solid curve in each plot shows the gluon ratio while the dashed curve shows the ratio of the $(u+\bar{u}+d+\bar{d})$ quark distributions.

similar x dependence: at $Q^2 = 4.5$ GeV^2, the ratio varies by less than 12% while the densities themselves vary by almost three orders of magnitude as x changes from 10^{-5} to 10^{-3}. The fall-off above 10^{-3} is a consequence of the minimum value of $\beta^{min} = x/0.01$, which is imposed to satisfy the diffractive requirement. It is also apparent that the ratios fall with increasing Q^2. The remarkable feature that the diffractive and inclusive densities in the proton have very similar x dependences ought to have some experimental consequences which we discuss next.

5. A LOOK AT DIFFRACTIVE DATA

Based on the previous discussion, for a hard scattering process (such as for DIS at HERA) we could expect:

- $\sigma^{diff}/\sigma^{tot} \sim f(\mu)$, but independent of x;
- $\sigma^{diff}/\sigma^{tot}$ should decrease with increasing $\mu^2 = Q^2$.

While the diffractive DIS data $F_2^{D(3)}$ were included in our original fit, it is still of interest to look at these data for indications of these two features, independent of the results of our fits.

5.1. Diffractive Data at HERA

ZEUS has presented the ratio of the diffractive cross section to the inclusive DIS cross section for e^+p scattering [8]. The ratio is independent of $W(= Q^2/x)$ at fixed Q^2 and, moreover, the fraction falls with increasing Q^2. This indicates that the diffractive and inclusive F_2 have the same W (or x) dependence at fixed Q^2.

Similarly, ZEUS data show that the ratio of the diffractive D^* cross section to the total inclusive D^* cross section in the same kinematic region is independent of Q^2 and $W = Q^2/x$ [7]. This also suggests that the diffractive and inclusive cross sections have the same W (or x) dependence.

5.2. Jet E_T Spectra at CDF and D0

For the HSF to apply, it is essential that only final-state interactions are present. Initial-state interactions between two hadrons occur early enough that they can affect the formation of the diffracted hadron. Typically, the soft, extra interactions that are present in hadron-hadron processes will give a suppression of diffractive cross sections. In spite of this, it is instructive to study kinematic distributions which might be insensitive to the overall normalization failures, but which are sensitive to the diffractive and inclusive parton densities.

Since, for dijet production, the momentum fractions of the two interacting partons are directly proportional to $E_T/\sqrt{s}$, a simple consequence of the similarity of diffractive and inclusive proton pdfs is that the E_T spectra of the dijets produced in inclusive, single diffraction and DPE processes should be the same.

Preliminary data from both CDF [9] and D0 [10] show the jet E_T spectra for the leading and second highest E_T jet for three data samples: an inclusive data set, a single diffraction data set and, finally, for a sample of events which satisfy the double pomeron exchange criteria. Apparently the inclusive, single diffractive and DPE jets have very similar jet E_T spectra.

6. CONCLUSIONS

Our conclusions can be summarized as follows:

- The diffractive proton pdfs at low Q^2 have the same x dependence as the inclusive proton pdfs;
- $pdf^{Diff}(x, Q^2) = c(Q^2) \cdot pdf^{Incl}(x, Q^2)$;
- The $c(Q^2)$ arises from evolution with different g, q distributions at Q_0^2.

The following measurements would constitute tests of the ideas discussed here:

- Diffractive DIS dijet production;
- Measure F_L^D as well as F_2^D;
- Study higher twist effects;
- Measure high statistics DDIS D^* and diffractive "direct photoproduction" D^* data.

In summary, we find the observation that diffractive processes can be described in terms of "diffractive proton parton distributions" which seem to have a very similar x dependence to that of the inclusive proton pdfs to be an appealing and simple picture.

REFERENCES

1. L. Alvero, J.C. Collins, J. Terron and J.J. Whitmore, Phys. Rev. **D59** (1999) 074022.
2. L. Alvero, J.C. Collins and J.J. Whitmore, hep-ph 9806340.
3. J.C. Collins, Phys. Rev. **D57** (1998) 3051.
4. H.L. Lai and W.K. Tung, Z. Phys. **C74** (1997) 463.
5. A. Donnachie and P.V. Landshoff, Phys. Lett. **B191** (1987) 309; Nucl. Phys. **B303** (1988) 634.
6. B.W. Harris and J. Smith, Phys. Rev. **D57** (1998) 2806.
7. ZEUS Collaboration, "Open Charm Production in Deep Inelastic Diffractive Scattering at HERA", contribution No. 785 to ICHEP98, Vancouver, July 1998.
8. ZEUS Collaboration, J. Breitweg et al., Eur. Phys. J. **C6** (1999) 43.
9. K. Terashi, CDF Collaboration, Fermilab-Conf-98/138-E, "Observation of Di-jet Production in Double Pomeron Exchange in $\bar{p}p$ Collisions at $\sqrt{s}$ 1800 GeV", Proc. of the 4th Workshop on Small-x and Diffractive Physics, 17-20 September, 1998, Fermilab, Batavia, Ill, p.407.
10. G. Alves, D0 Collaboration, "Jet Production with Two Rapidity Gaps", Proc. of the 4th Workshop on Small-x and Diffractive Physics, 17-20 September, 1998, Fermilab, Batavia, Ill, p.417.