New developments in QCD analysis of inclusive diffraction at HERA

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A large collection of results for the diffractive dissociation of virtual photons, $\gamma^\star p \to Xp$, have been obtained with the H1 and ZEUS detectors at HERA. Different experimental techniques have been used, by requiring a large rapidity gap between X and the outgoing proton, by analysing the mass distribution, M_X, of the hadronic final state, as well as by directly tagging the proton. A reasonable compatibility between those techniques and between H1 and ZEUS results have been observed. Some common fundamental features in the measurements are also present in all data sets. Diffractive PDFs can give a good account of those features. Ideas and new developments are discussed in these proceedings.

1 Inclusive Diffraction at HERA

One of the most important experimental result from the DESY ep collider HERA is the observation of a significant fraction of events in Deep Inelastic Scattering (DIS) with a large rapidity gap (LRG) between the scattered proton, which remains intact, and the rest of the final system. This fraction corresponds to about 10% of the DIS data at $Q^2 = 10$ GeV^2. In DIS, such events are not expected in such abundance, since large gaps are exponentially suppressed due to color string formation between the proton remnant and the scattered partons. Events are of the type $ep \to eXp$, where the final state proton carries more than 95 % of the proton beam energy. A photon of virtuality Q^2, coupled to the electron (or positron), undergoes a strong interaction with the proton (or one of its low-mass excited states Y) to form a hadronic final state system X of mass M_X separated by a LRG from the leading proton (see Fig. 1). These events are called diffractive (see [2] for more details). In such a reaction, $ep \to eXp$, no net quantum number is exchanged and the longitudinal momentum fraction $1 - x_{I\!P}$ is lost by the proton. Thus, the mongitudinal momentum $x_{I\!P} P$ is transfered to the system X. In addition to the standard DIS kinematic variables and $x_{I\!P}$, a diffractive event is also often characterised by the variable $\beta = x_{Bj}/x_{I\!P}$, which takes a simple interpretation in the parton model discussed in the following.

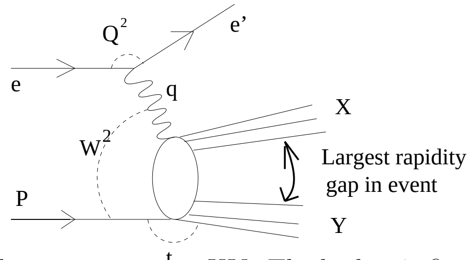

Figure 1: Illustration of the process $ep \to eXY$. The hadronic final state is composed of two distinct systems X and Y, which are separated by the largest interval in rapidity between final state hadrons.

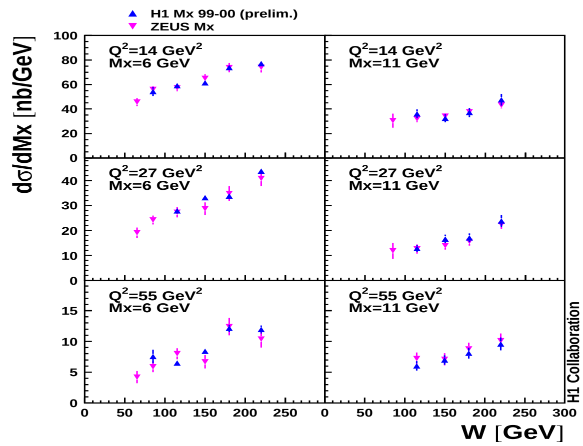

Figure 2: Cross sections of the diffractive process $\gamma^* p \to p' X$, differential in the mass of the diffractively produced hadronic system X (M_X), are presented as a function of the centre-of-mass energy of the $\gamma^* p$ system W. Measurements at different values of the virtuality Q^2 of the exchanged photon are displayed. We observe a behaviour of the form $\sim W^{0.6}$ for the diffractive cross section, compatible with the dependence expected for a hard process.

In order to compare diffractive data with perturbative QCD models, or parton-driven models, the first step is to show that the diffractive cross section shows a hard dependence in the centre-of-mass energy W of the $\gamma^* p$ system. In Fig. 2, we observe a behaviour of the form $\sim W^{0.6}$, compatible with the dependence expected for a hard process. This observation is obviously the key to allow further studies of the diffractive process in the context of perturbative QCD. Events with the diffractive topology can be studied in terms of Pomeron trajectory exchanged between the proton and the virtual photon. In this view, these events result from a colour-singlet exchange between the diffractively dissociated virtual photon and the proton. Extensive measurements of diffractive DIS cross sections have been made by both the ZEUS and H1 collaborations at HERA, using different experimental techniques [2]. Of course, the comparison of these techniques provides a rich source of information to get a better understanding of the experimental gains and prejudices of those techniques.

2 Diffractive PDFs

A diffractive structure function $F_2^{D(3)}$ can then be defined as a sum of two factorized contributions, corresponding to a Pomeron and secondary Reggeon trajectories:
$F_2^{D(3)}(Q^2, \beta, x_{I\!P}) = f_{I\!P/p}(x_{I\!P}) F_2^{D(I\!P)}(Q^2, \beta) \; + f_{I\!R/p}(x_{I\!P}) F_2^{D(I\!R)}(Q^2, \beta)$, where $f_{I\!P/p}(x_{I\!P})$ is the Pomeron flux. It depends only on $x_{I\!P}$, once integrated over t, and $F_2^{D(I\!P)}$ can be interpreted as the Pomeron structure function, depending on β and Q^2. The other function, $F_2^{D(I\!R)}$, is an effective Reggeon structure function taking into account various secondary Regge contributions which can not be separated. The Pomeron and Reggeon fluxes are assumed to follow a Regge behaviour with linear trajectories $\alpha_{I\!P,I\!R}(t) = \alpha_{I\!P,I\!R}(0) + \alpha'_{I\!P,I\!R} t$,

such that

$$f_{I\!P/p,I\!R/p}(x_{I\!P}) = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{I\!P,I\!R}t}}{x_{I\!P}^{2\alpha_{I\!P,I\!R}(t)-1}} \mathrm{d}t. \tag{1}$$

Then, following [3], diffractive PDFs can be extracted. In Fig. 3 we present the result for these diffractive PDFs (quark singlet and gluon densities), obtained using the most recent inclusive diffractive cross sections presented in [2]. In Fig. 3, the complete sets of published diffractive measurements are included in the QCD fits for both experiments H1 and ZEUS. Note also that in all QCD fits, we let the global relative normalisation of the data set as a free parameter (with respect to H1 LRG sample) [3]. The typical uncertainties for the diffractive PDFs in Fig. 3 ranges from 5% to 10% for the singlet density and from 10% to 25% for the gluon distribution, with 25% at large z (which corresponds to large β for quarks) [3]. Within these uncertainties, a nice agreement between diffractive PDFs extracted from H1 and ZEUS data is obtained. This shows in an indirect way that data sets are well compatible and the underlying dynamics is similar in all sets.

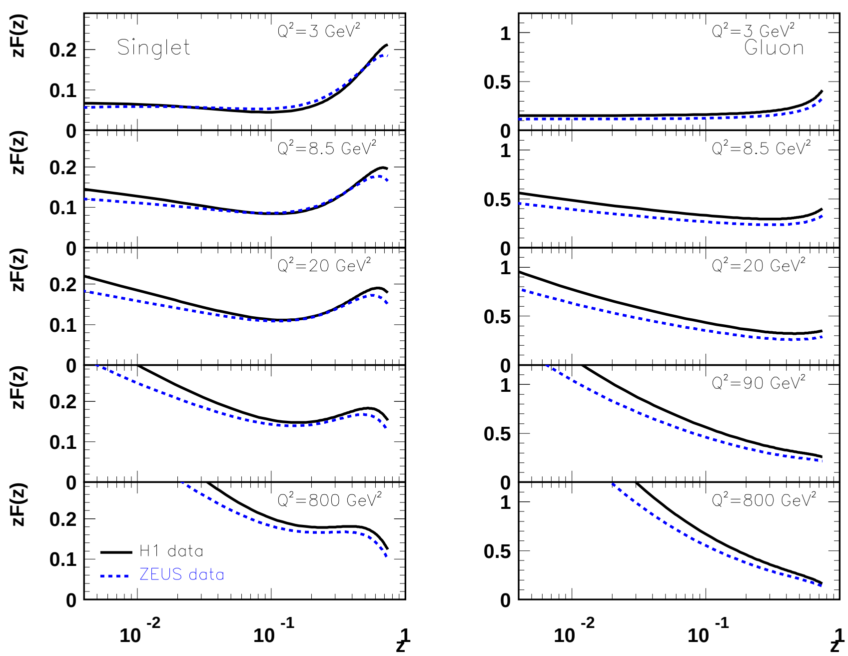

Figure 3: Singlet and gluon distributions of the Pomeron as a function of z, the fractional momentum of the Pomeron carried by the struck parton, derived from QCD fits on H1 and ZEUS inclusive diffractive data (LRG)[2]. The parton densities are normalised to represent $x_{I\!P}$ times the true parton densities multiplied by the flux factor at $x_{I\!P} = 0.003$ [3]. A good agreement is observed between both diffractive PDFs, which indicates that the underlying QCD dynamics derived in both experiments is similar.

Then, an important conclusion is the prediction for the longitudinal diffractive structure function. In Fig. 4 we display this function with respect to its dependence in β (Fig. 4 (a)) and the ratio R of the longitudinal to the transverse components of the diffractive structure function (Fig. 4 (b)).

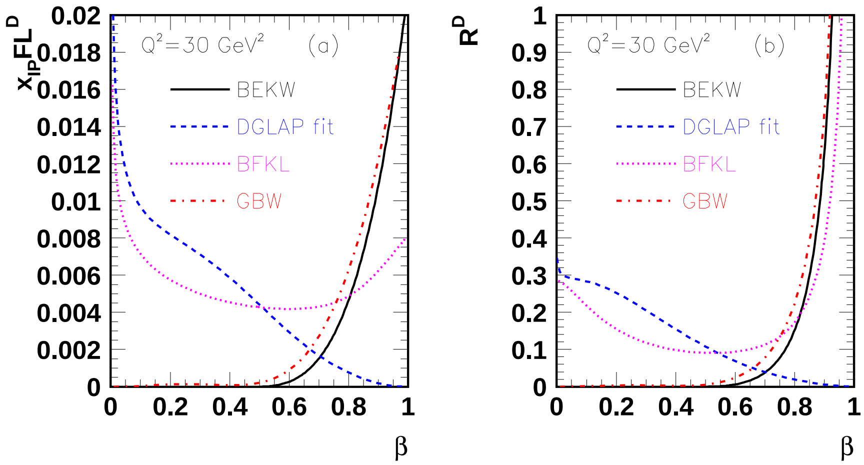

Figure 4: Predictions for $x_{I\!P} F_L^D$ and $R^D = \frac{F_L^D}{F_2^D - F_L^D}$ as a function of β at $Q^2 = 30$ GeV^2 and $x_{I\!P} = 10^{-3}$ [3]. The dashed line prediction refers to the diffractive PDFs analysis discussed in this part. Other curves represent dipole model calculations.

Note that diffractive distributions are process-independent functions. They appear not only in inclusive diffraction but also in other processes where diffractive hard-scattering factorisation holds. The cross section of such a process can be evaluated as the convolution of the relevant parton-level cross section with the DPDFs. For instance, the cross section for charm production in diffractive DIS can be calculated at leading order in α_s from the $\gamma^* g \to c\bar{c}$ cross section and the diffractive gluon distribution. An analogous statement holds for jet production in diffractive DIS. Both processes have been analysed at next-to-leading order in α_s and are found to be consistent with the factorisation theorem. A natural question to ask is whether one can use the DPDFs extracted at HERA to describe hard diffractive processes such as the production of jets, heavy quarks or weak gauge bosons in $p\bar{p}$ collisions at the Tevatron. Using results on diffractive dijet production from the CDF collaboration [4] compared to the expectations based on the DPDFs from HERA, a spectacular discrepancy has been observed [3]. Indeed, the fraction of diffractive dijet events at CDF is a factor 3 to 10 smaller than would be expected on the basis of the HERA data. The same type of discrepancy is consistently observed in all hard diffractive processes in $p\bar{p}$ events. In general, while at HERA hard diffraction contributes a fraction of order 10% to the total cross section, it contributes only about 1% at the Tevatron. This observation of

QCD-factorisation breaking in hadron-hadron scattering can be interpreted as a survival gap probability or a soft color interaction which needs to be considered in such reactions. In fact, from a fundamental point of view, diffractive hard-scattering factorization does not apply to hadron-hadron collisions. Attempts to establish corresponding factorization theorems fail, because of interactions between spectator partons of the colliding hadrons. The contribution of these interactions to the cross section does not decrease with the hard scale. Since they are not associated with the hard-scattering subprocess, we no longer have factorization into a parton-level cross section and the parton densities of one of the colliding hadrons. These interactions are generally soft, and we have at present to rely on phenomenological models to quantify their effects [4]. The yield of diffractive events in hadron-hadron collisions is then lowered precisely because of these soft interactions between spectator partons (often referred to as reinteractions or multiple scatterings). They can produce additional final-state particles which fill the would-be rapidity gap (hence the often-used term rapidity gap survival). When such additional particles are produced, a very fast proton can no longer appear in the final state because of energy conservation. Diffractive factorization breaking is thus intimately related to multiple scattering in hadron-hadron collisions. Understanding and describing this phenomenon is a challenge in the high-energy regime that will be reached at the LHC [5].

3 Summary and outlook

We have presented and discussed the most recent results on extraction of diffractive PDFs from the HERA experiments. A large collection of data sets and diffractive cross sections are published, which present common fundamental features in all cases. The different experimental techniques, for both H1 and ZEUS experiments, provide compatible results, with still some global normalisation differences of about 10%. DPDFs give a good account of the main features of the all diffractive data sets. This is a very important message from HERA that diffractive DPFs are well compatible for both experiments. Of course, there is still much to do on the experimental side with large statistics analyses, in order to obtain a better understanding of data and backgrounds. QCD fits of these data will provide an interesting tool for the purpose of combining data. This is a major challenge for HERA experiments in the next year.

References

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