Factorization and factorization breaking in diffraction at HERA

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Abstract. A recent progress is reviewed in our understanding of diffractive processes at HERA. New precision measurements are now available from both H1 and ZEUS collaborations, from which diffractive parton distribution functions are determined. They are used to test QCD factorization in diffractive production of charm and dijets.

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Introduction

A significant progress has been achieved over the last decade in understanding the nature of *diffractive phenomena* at high energies. This is to a large extent due to the electron-proton collider HERA, which for the first time offers the possibility for the partonic structure of colour singlet exchange to be probed in hard diffractive deep-inelastic scattering (DIS).

At the hadronic level diffraction is best described in the framework of Regge formalism[1, 2] as a t-channel exchange of a leading trajectory with the vacuum quantum numbers, named *Pomeron*. Specific interest to diffraction as a 'physics of Pomeron' is related to the fact that the Pomeron exchange asymptotically dominates over all other contributions to the scattering amplitude, and thus represents the essence of strong interactions in high energy limit. Translating to the modern partonic language this reveals that colourless exchange is important in low-x regime (which is high energy limit of QCD) where gluons expect to dominate. Since the diffractive cross section, being proportional to the gluon density squared, rises with energy faster than the total cross section unitarity correction effects, e.g. in a form of gluon saturation, are expected to be first seen in diffraction. Hence an interesting question is: can this be observed already at HERA?

Another aspect in which diffraction may play a key rôle is an interplay between soft and hard processes. Since both short distance and long distance physics contribute to diffractive DIS, HERA has high potential to provide new insight into non-perturbative QCD phenomena, as well as to bridge soft (Regge) and hard (pQCD) domains.

The central problem in hard diffraction is the question of *QCD factorization*, i.e. the question whether it is possible to describe diffractive cross section by a convolution of the diffractive parton distribution functions (DPDFs) with universal partonic cross sections. For diffractive DIS QCD factorization has been proven by Collins[3] while it fails for hadron induced reactions. In addition it is important to test a conjecture of

Regge factorization[4] which assumes that the diffractive cross section can be expressed as a product of Pomeron flux and its structure function. In this paper both hard QCD and Regge factorization hypotheses are confronted with recent HERA data[5, 6, 7, 8, 9].

Testing Regge factorization in inclusive diffraction

Several experimental techniques are used to measure diffractive processes $ep \rightarrow eXY$ at HERA, where a single proton or low mass excitation system Y is separated from the final state X by large rapidity gap. They have different advantages and drawbacks and are complementary to each other. Most clean, but statistically limited sample is provided by so called LPS method in which scattered proton in the forward direction is detected directly by *Roman Pot* technique. To obtain high statistics sample one can use characteristic properties of the hadronic final state. H1 and ZEUS follow slightly different approaches trying to to fully utilize their detector capabilities.

H1 method is based on the requirement of the large rapidity gap separating the leading baryon system Y from the photon dissociation system X. The rapidity gap is positively identified by the absence of activity in pseudorapidity interval $3.2 < \eta < 7.5$, covered by various detector components. In this approach non-diffractive background is small and can be estimated using Monte Carlo simulation.

The extraction of the diffractive contribution in ZEUS is performed using so called M_X method, which is based on the fact that diffractive and non-diffractive final states have very different $\ln M_X^2$ distributions. The non-diffractive contribution exhibiting exponential fall-off towards lower M_X values is extrapolated underneath the diffractive plateau and statistically subtracted from the total M_X distribution.

Inclusive diffractive cross sections as a function of longitudinal momentum fraction of the colour singlet exchange relative to the incoming proton, $x_{I\!P}$, as measured by different techniques in the intermediate Q^2 range are compared in Fig.1. Data show fair agreement in the bulk of the phase space. However some systematic differences are present at low M_X. Moreover, less steep Q^2 dependence is observed in ZEUS M_X sample as compared to H1 LRG data.

One of the basic predictions in Regge model is a specific asymptotic behaviour of the total, elastic and diffractive cross sections with energy, W, which is controlled by the value of intercept of the universal Pomeron trajectory, $\alpha_{I\!P}(t)$ at $t = 0$. In addition, if Regge factorization holds the Pomeron flux $f_{I\!P}(x_{I\!P}, t) = x_{I\!P}^{1-2\alpha_{I\!P}(t)} e^{bt}$ (and hence $\alpha_{I\!P}(0)$) should not depend on $\beta = x/x_{I\!P}$ and Q^2. Fig.2 summarizes the Q^2 dependence of $\alpha_{I\!P}(0)$ as extracted using Regge motivated fits from diffractive and inclusive DIS data. In the inclusive case proton structure function can be parameterised at low $x < 0.01$ in form of $F_2(x, Q^2) = cx^{-\lambda(Q^2)}$ with $\lambda = \alpha_{I\!P}(0) - 1$. In diffractive DIS $\alpha_{I\!P}(0)$ can be obtained from W, or equivalently from $x_{I\!P}$-dependence of the diffractive cross section. One can see, that the data cannot be described by the universal factorizable Pomeron.

NLO DGLAP QCD fit[10] is performed to inclusive diffractive cross sections as measured by H1 and ZEUS. Resulting DPDFs are shown in Fig.3. While singlet component is similar at low Q^2, H1 and ZEUS gluon distributions differ in normalization by factor of two, reflecting different Q^2 dependence in the original cross sections.

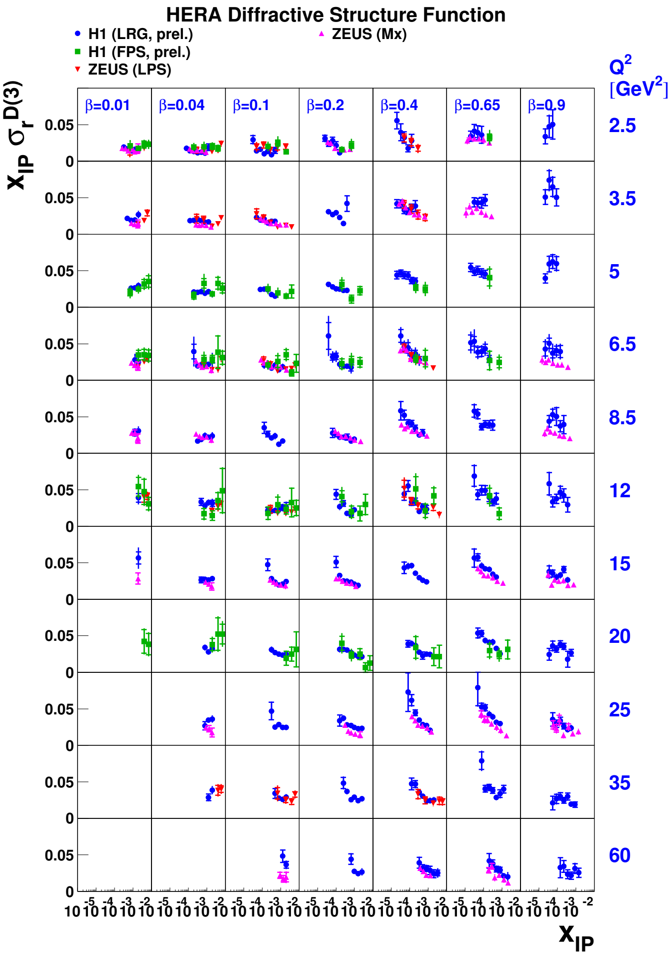

FIGURE 1. Diffractive reduced cross sections, measured in four different samples, as a function of $x_{\mathbb{P}}$ in bins of β and Q^2. All data are scaled to $M_Y < 1.6$ GeV range and transported to H1 LRG bin centers.

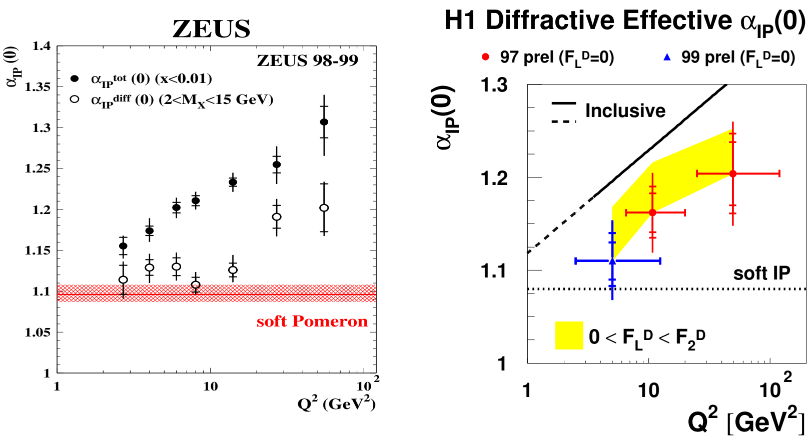

FIGURE 2. The intercept of the Pomeron trajectory, $\alpha_{\mathbb{P}}(0)$, as a function of Q^2 in diffractive and inclusive DIS, as determined by ZEUS(left) and H1 (right).

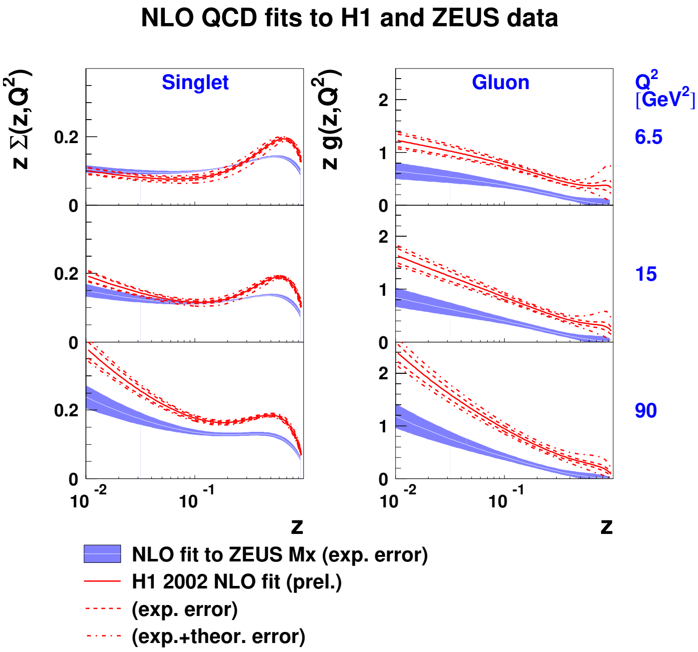

FIGURE 3. Diffractive parton dencities obtained from the NLO QCD fits[10] and normalized such that the Pomeron flux is unity at $x_{I\!P} = 0.003$.

Testing QCD factorization in diffractive final states

In the following the H1 diffractive PDFs[10] are used to describe more exclusive final states, such as charm and dijets production, in which hard scale makes partonic cross sections perturbatively calculable and hence allows to test QCD factorization and the universality of the extracted DPDFs.

Charm production is tagged via $D^{*\pm}$ in diffractive DIS. The cross section is determined for the kinematic region $2 < Q^2 < 100$ GeV^2, $0.05 < y < 0.7$ and $p_{T,D^*} > 2$ GeV. The NLO QCD prediction is calculated using program HVQDIS[11] interfaced to the H1 DPDFs, with renormalisation and factorization scales set to $\mu_f^2 = \mu_r^2 = Q^2 + 4m_c^2$ and $m_c = 1.5$ GeV. Fig.4 (left) shows that H1 and ZEUS measurements are in agreement and both are well described by NLO QCD calculations. This supports the validity of QCD factorization in diffractive DIS. Same conclusion can be drawn from the diffractive dijets production in DIS regime[8] which is compared to NLO QCD calculations using DISENT[12] program on Fig.4 (right).

Note, that in spite of overall good agreement withing systemetic uncertainties the calculations overestimate the cross section at high $z_{I\!P}^{jets}$. This indicates a potential of the data to further constrain diffractive gluon density.

Contrary to DIS a suppression factor of ~ 2 is observed when comparing H1 diffractive dijets in photoproduction to NLO predictions[13]. Such a supprerssion (sometimes also called the *gap survival probability*) is expected theoretically in resolved photoproduction and can be estimated using eikonal models based on s-channel unitarity [14].

In order to study the behaviour of direct and resolved component separately, the dijet

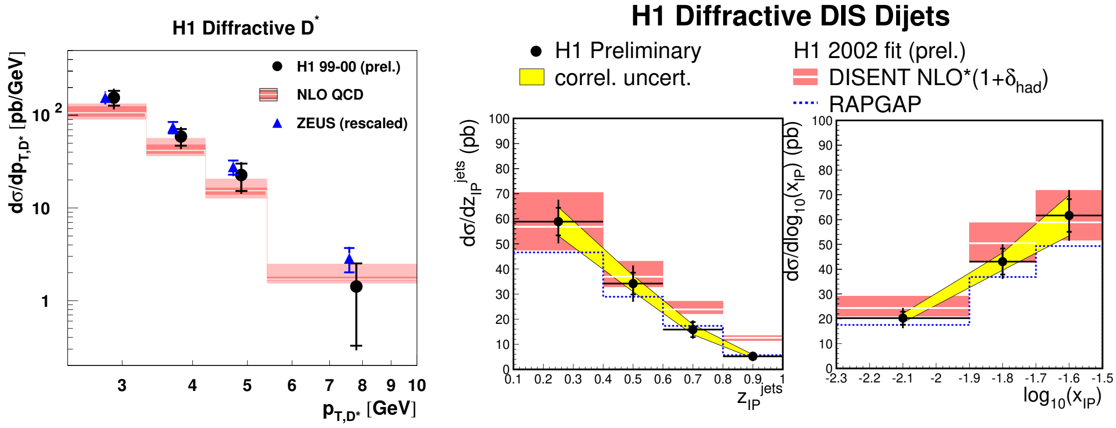

FIGURE 4. Differential $D^{*\pm}$ cross section at $x_{I\!P} < 0.04$ in diffractive DIS as a function of p_{T,D^*}, compared to NLO QCD predictions (left). Differential dijet cross sections in diffractive DIS compared to NLO QCD predictions (right).

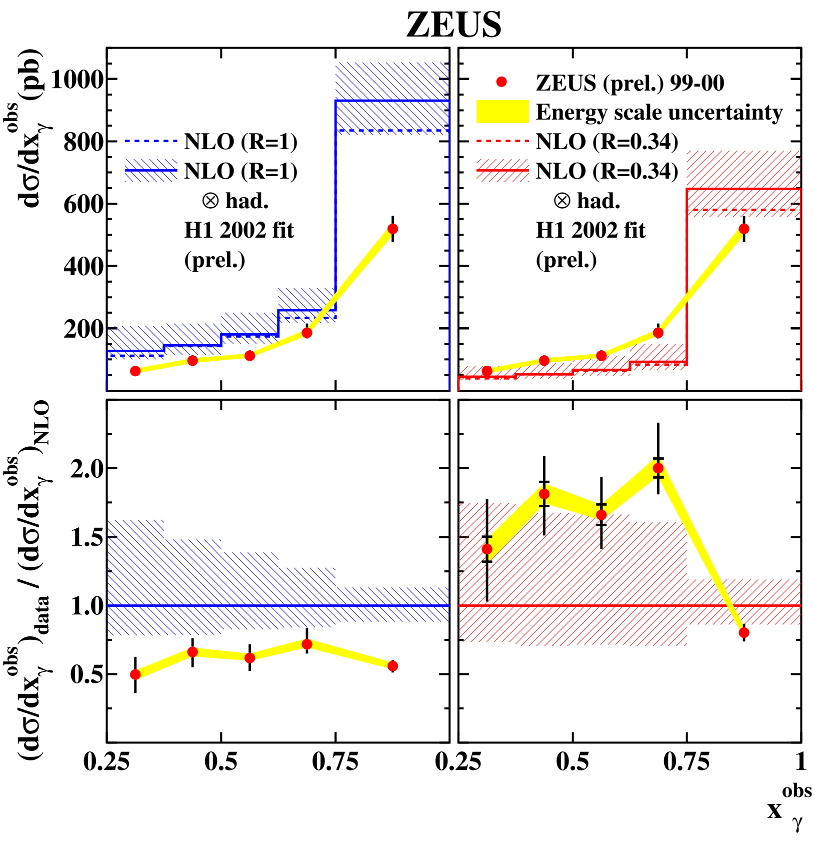

FIGURE 5. Differential dijet cross sections and their ratios to NLO QCD predictions[15] in diffractive photoproduction as a function of x_γ^{obs} when applying resolved component suppression by factor of R.

cross section is measured as a function of $x_\gamma^{obs} = \sum_{jets}(E_T^{jet} e^{-\eta^{jet}})/2yE_e$. The result as shown in Fig.6 disfavours the suppression of only the resolved contribution by a factor of $R = 0.34$[14, 15] but rather suggests a global x_γ^{obs} independent suppression by a factor of ~ 2. Note however that this conclusion strongly depends upon the choice of DPDFs[16].

SUMMARY

New generation of diffractive parton distributions together with their uncertainties are determined from HERA data in NLO QCD framework. They are used to test factorization properties of diffraction in different reactions. Despite measured F_2^D are in fair agreement between the two HERA experiments remaining differences lead to approximately two times different gluon in diffractive PDFs. This has to be clarified with new data.

Q^2 dependence of the Pomeron intercept suggests Regge factorization breaking in DIS regime. Energy dependence of the diffractive cross section has no simple explanation at the moment. It may indicate the onset of unitarity corrections (or saturation effect) is already seen in diffraction at HERA. Alternatively, it could be a manifestation of a complicated interplay between soft and hard phenomena in diffractive DIS.

NLO predictions for diffractive final states strongly depend upon specific choice of diffractive parton density functions. When using H1 DPDFs both diffractive charm and dijets production in DIS support QCD factorization. In diffractive photoproduction QCD factorization is broken, showing at the moment global x_γ independent suppression factor of ~ 2, contrary to the most plausible theoretical expectation.

In spite of the recent progress a complete understanding of the nature of colour singlet exchange remains a major challenge in QCD.

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