Low x and diffraction at HERA

Alice Valkárová
on behalf of H1 and ZEUS Collaborations

Institute of Particle and Nuclear Physics, Faculty of Mathematics and Physics of Charles University
180 00 Praha 8, V Holesovickách 2, Czech Republic

E-mail: alice.valkarova@mff.cuni.cz

High statistics measurements of the diffractive reduced cross section $\sigma^D$ from the H1 collaboration are presented which make use of two different experimental methods to achieve the largest possible coverage of the kinematic phase space at HERA. The diffractive dijet cross sections for photoproduction and deep inelastic scattering were studied with emphasis of studying of factorisation properties of diffractive processes.

Keywords: ep interactions; diffraction; dijet cross sections; QCD collinear factorisation.

1. Introduction

Since the sixties, diffraction phenomena are studied in particle physics, for instance in proton-proton or antiproton-proton scattering. Quantum Chromodynamics (QCD) is a very successful theory in the regime of short distances, corresponding to small values of the strong coupling constant $\alpha_s$, where perturbative methods can be applied, hadronic cross sections are often governed by long range forces, where a satisfactory theoretical description is still missing.

The first observation of diffractive electron-proton deep-inelastic scattering (DIS) at HERA in 1993 has renewed the interest in understanding such. The first HERA data confirmed the existence of a hard component in diffractive interactions as suggested by Ingelman and Schlein and they also verified also observations of jets at UA8 experiment.

In diffractive ep interactions the proton stays intact or dissociates into a low mass state ($Y$), while the photon may dissociate into a hadronic state $X$, $\gamma^* p \to Xp'(Y')$. The systems are separated by a large rapidity gap (LRG). The diffractive exchange object (usually called pomeron) has vacuum quantum numbers and carries away a fraction $x_p$ of the initial proton longitudinal momentum. The four-momentum transfer squared from the incoming to the outgoing proton is denoted $t$.

Several theoretical approaches have been proposed to describe the dynamics of diffractive DIS. A general theoretical framework is provided by the QCD collinear factorisation theorem for DIS cross sections. This implies that the concept of diffractive parton distribution functions (DPDFs) may be introduced. Empirically, an Regge-type proton vertex factorisation has been succesful in describing diffractive DIS, whereby the variables which describe the proton vertex factorise from those
describing the hard interaction. The dependencies of the diffractive reduced cross section $\sigma^D_\gamma$ on $\beta$ (fractional momentum of the quark struck by $\gamma^*$) and on the virtuality $Q^2$ can thus be treated in a manner similar to inclusive DIS through the application of the DGLAP parton evolution equations.

Diffractive parton densities have been determined from QCD fits to inclusive diffractive cross section measurements in DIS. The gluon density is weakly constrained by the inclusive data. Therefore further fits exploited in addition diffractive dijet and charm production in DIS, as these processes are dominated by boson gluon fusion. The resulting parametrisations are: H1 2007 fit Jets and ZEUS fit SJ.

In Fig. 1, a comparison of three frequently used DPDF sets is shown as a function of $z$, the partonic longitudinal four-momentum fraction with respect to the pomeron.

Fig. 1. The diffractive quark singlet and gluon densities for the squared factorisation scale $\mu^2 = 25$ GeV$^2$ in the region $M_Y < 1.6$ GeV, $|t| < 1$ GeV$^2$ and for $x_F = 0.01$. ZEUS fit SJ is multiplied by a factor of 1.2 in order to accommodate for differences in the definition of diffractive cross section by H1 and ZEUS collaborations - see e.g. 3.

As seen from Fig. 1 most of the momentum of the diffractive exchange is carried by gluons.

2. Inclusive diffraction at HERA

In the majority of previous analyses diffractive events were selected on the basis of the presence of a large rapiditity gap (LRG) between the leading proton and hadronic final state X. A complementary way to select diffractive events is by direct measurements of the outgoing proton in forward proton spectrometers. The forward
sections is usually expressed by means of suppression factor, defined as a ratio of two cross sections where the rapidity gap can be populated by soft particles from additional soft and higher twist corrections are neglected.

The proton remains intact or where dissociates into a system of low mass.

Data at the nominal proton beam energy $E_p = 920$ GeV from the HERA I and II running periods have been analysed by H1 collaboration to extract diffractive reduced cross section $\sigma_r^D$ in a wide kinematic range, using LRG detection method and two H1 forward proton spectrometers FPS and VFPS\textsuperscript{7}. In Fig. 2 the full set of data as a function of $Q^2$ in bins of $\beta$ is shown. The LRG data and DPDF fit B are corrected to $M_Y = M_{\text{proton}}$ using a global normalisation factor of 0.81. The measurements compare well with each other and with DPDF fit B prediction.

3. Tests of QCD factorisation

QCD factorisation holds for inclusive and dijet processes, provided $Q^2$ is high enough and higher twist corrections are neglected.

It is known however that QCD factorisation may be broken in diffractive processes where the rapidity gap can be populated by soft particles from additional soft interactions of remnants and ingoing hadrons. Such a factorisation breaking was observed in diffractive hadron-hadron interactions\textsuperscript{8,9}. The factorisation breaking is usually expressed by means of suppression factor, defined as a ratio of two cross sections $S^2 = \frac{\sigma(\text{data})}{\sigma(\text{theory})}$, where the theory is based on QCD collinear factorisation, here represented by NLO QCD calculations.
Fig. 3. The differential DIS dijet cross section as a function of mean $<P_T^*>$ and $z_{IP}$ compared to NLO QCD calculations.

The factorisation is expected to be valid for dijet production in DIS and was tested by both H1 and ZEUS collaborations. Diffractive events were selected with the help of criteria of LRG and using the forward proton spectrometer (FPS). The measured cross sections were found to be in good agreement with NLO QCD calculations.

A new measurement with about six times higher statistics than previous measurements was provided by H1 using the data of HERA II and LRG method of selection of diffractive events. The measurement was performed for $x_{IP} < 0.03$, $4 < Q^2 < 80$ GeV$^2$ and events with jets with transverse momenta $P_{T,1} > 5.5$ GeV and $P_{T,2} > 4$ GeV$^2$. The differential cross sections as a function of the mean jet $<P_T^*>$ and of $z_{IP}$ are shown in Fig. 3. Data are well described by NLO QCD predictions and the previous HERA measurements are fully confirmed.

Dijets in diffractive photoproduction have been measured by H1$^{11,12}$ and ZEUS$^{13}$ previously. In these measurements diffractive events were selected using the LRG method. The ZEUS analysis covered a slightly different kinematic region e.g. by requiring higher transverse jet energies than for H1. The overall suppression factor of the data to the NLO QCD predictions was found to be about 0.6 in case of the H1 analyses but consistent with unity in case of the ZEUS measurement.

A new measurement of diffractive dijet cross section in photoproduction events with leading final state proton detected in Very Forward Proton Spectrometer (VFPS) was performed by H1 collaboration in photoproduction ($Q^2 < 2$ GeV$^2$) and DIS ($4 < Q^2 < 80$ GeV$^2$)$^{14}$. A reliable method to test QCD factorisation, first applied at HERA in$^{11}$, was given by exploring the double-ratio of measured to predicted cross sections in diffractive photoproduction to the corresponding ratio in diffractive DIS. In this double ratio many experimental systematic and theo-
Fig. 4. DIS and photoproduction integrated cross sections normalised to the NLO QCD theoretical calculations are shown as a white line. The double ratio of data over NLO QCD calculations for photoproduction to data over NLO QCD calculations for DIS is presented as a white line in the last row.

retical uncertainties cancel. For this purpose the identical kinematic region for DIS and photoproduction dijets (except for $Q^2$) was used. The jet finding algorithm is applied in the laboratory frame for photoproduction and in $\gamma^*p$ frame for DIS. The leading and sub-leading jets are required to have $E_{\text{jet}1}^T > 5.5$ GeV and $E_{\text{jet}2}^T > 4$ GeV, respectively \(^a\). Theoretical predictions based on factorisation theorem were performed by the NLO QCD calculations adopted for diffractive photoproduction and DIS. In both photoproduction and DIS are shapes of differential distributions properly described by a theory. It was found however that for photoproduction the NLO QCD predictions lie systematically above the data resulting to the suppression factor about 0.6. For DIS dijets the NLO QCD calculations agree within theoretical uncertainties with data. Both data/NLO ratios are shown in Fig. 4.

Integrated over the measured kinematic range the double ratio of data over NLO QCD calculations for photoproduction to data over NLO QCD calculations for DIS is:

$$\frac{(\text{DATA}/\text{NLO})_{\gamma^*p}}{(\text{DATA}/\text{NLO})_{\text{DIS}}} = 0.55 \pm 0.10 \text{ (data)} \pm 0.02 \text{ (theor.)}$$ (1)

and is shown in Fig. 4. As shown in Figure 5 no kinematic dependence of the double ratio is observed as a function of both $z_{\gamma^*p}$ and $E_{\text{jet}1}^T$.

4. Summary

High statistics measurements of the diffractive reduced cross section $\sigma^D_f$ from the H1 collaboration are presented which make use of two different experimental meth-

\(^a\)Quantities in the $\gamma^*p$ frame are denoted by asterisk “*”.\n
Diffractive dijets cross sections in DIS using LRG method of the selection of diffractive events was measured by H1. With a six times larger statistics of data a good agreement of NLO QCD calculations with data was obtained. Diffractive dijets cross sections in photoproduction and in DIS with the leading proton detected by proton spectrometer were measured to cross check the previous statements about the factorisation breaking. The double ratio of measured to predicted cross sections in diffractive photoproduction to corresponding ratio in DIS is 0.55 indicating that QCD factorisation may be broken in diffractive dijet photoproduction.

References