Diffraction at HERA

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Precision measurements of diffraction have been performed by the H1 and ZEUS experiments at the HERA collider with high statistics for a wide kinematic range of photon virtuality Q^2. The diffractive parton densities are extracted by performing the NLO DGLAP QCD fits to diffractive data and can be used to test QCD factorisation with diffractive final states.

1 Introduction

Diffraction, in which the proton or a low-mass nucleonic system emerges from the interaction with almost the full energy of the incident proton, is mediated by the exchange of a colour singlet carrying the quantum numbers of the vacuum, called the Pomeron. It has been observed by the presence of a large rapidity gap between the proton and the rest of the final state, which is not exponentially suppressed.

With increasing statistics, improved instruments and better detector understanding, the H1 and ZEUS experiments at HERA have measured the diffractive processes for many different final states. Diffractive measurements at HERA are necessary for understanding the low-x structure of the proton and also important for the interpretation of LHC results.

2 Measurements of inclusive diffraction

Inclusive diffractive events have been extracted using the hadronic mass spectrum observed in the central detector (M_X method [1]), the presence of a large rapidity gap (LRG method [2,3]), or the detection of the leading protons which carry a large fraction of the incoming proton beam energy (H1 FPS [4], ZEUS LPS methods [3]). While additional contributions from Reggeon exchange are exponentially suppressed when using the M_X method, the selections based on LRG or on a leading proton may include these contributions. The LPS method can reconstruct the squared four-momentum transfer at the proton vertex t under the limited LPS acceptance. The other two methods based on the hadronic activity in the forward detector only provide the results integrated over t and therefore contain the contribution from the nucleon dissociation to $M_N < 2.3$ GeV ($M_N < 1.6$ GeV) for ZEUS (H1) measurement.

Highlights are presented mainly from the ZEUS diffractive deep inelastic scattering (DIS) results obtained with the M_X method which were recently published [1]. They have been obtained with data taken in 1998-1999 for $2.2 < Q^2 < 80$ GeV^2 (FPC I) and in 1999-2000 for $25 < Q^2 < 320$ GeV^2 (FPC II). The diffractive cross section, $d\sigma^{\rm diff}_{\gamma^* p\to XN}/dM_X$ with $M_N < 2.3$ GeV was studied as a function of the hadronic centre-of-mass W, of the mass M_X of the diffractively produced system X and for different Q^2 values. The agreement between both results is observed

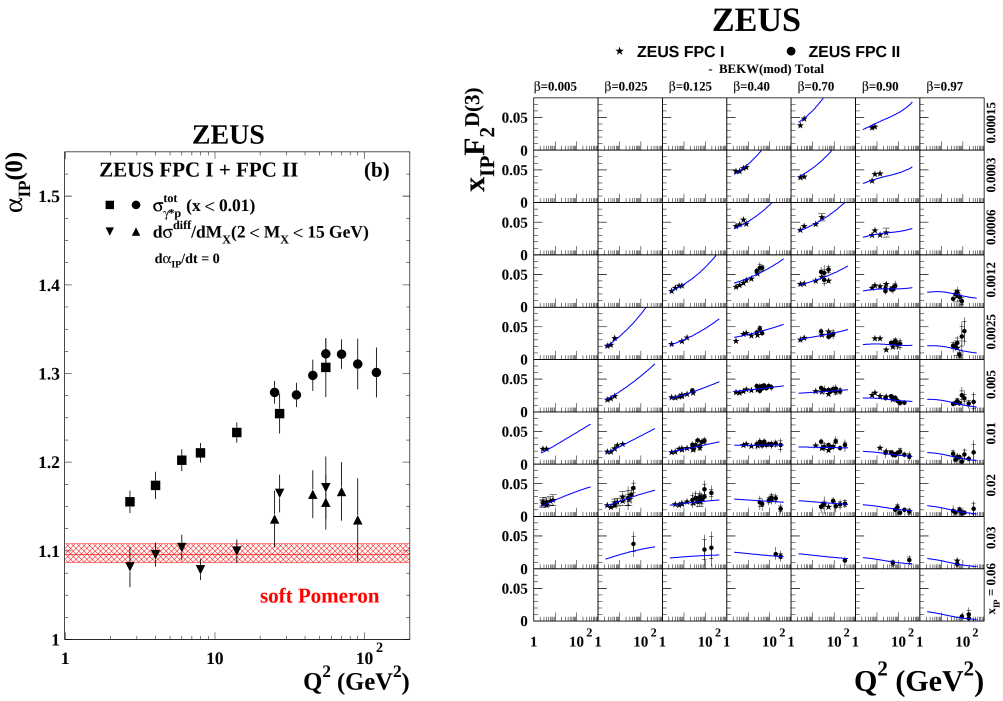

Figure 1: (left) The intercepts of the Pomeron trajectory, $\alpha_{I\!P}^{\rm tot}(0)$ and $\alpha_{I\!P}^{\rm diff}(0)$ vs. Q^2 for $\alpha_{I\!P}/dt = \alpha'_{I\!P} = 0$ GeV^{-2}. (right) $x_{I\!P} F_2^{\rm D(3)}$ vs. Q^2 for different values of β and $x_{I\!P}$. The curves are the results of BEKW(mod) fit. Data are shown from the ZEUS FPC I and FPC II analyses.

within the systematic errors. For $M_X < 2$ GeV, the diffractive cross section is rather constant with W while at higher M_X, a strong rise with W is observed for all values of Q^2. The intercept of the Pomeron trajectory was calculated using the W dependence of the diffractive cross section. As shown in Fig. 1-(left), for $Q^2 < 20$ GeV^2, $\alpha_{I\!P}^{\rm diff}(0)$ is compatible with the soft-Pomeron value, while a substantial rise with Q^2 above the soft-Pomeron value is observed for $Q^2 > 30$ GeV^2. The $\alpha_{I\!P}^{\rm diff}(0)$ values are lower than those from the total $\gamma^* p$ process, with $[\alpha_{I\!P}^{\rm diff}(0) - 1]/[\alpha_{I\!P}^{\rm tot}(0) - 1] \approx 0.5 - 0.7$. Therefore, these processes cannot be described simultaneously by a single Pomeron. The ratio of the diffractive cross section to the total $\gamma^* p$ cross section, $r = \sigma^{\rm diff}(0.28 < M_X < 35$ GeV, $M_N < 2.3$ GeV$)/\sigma^{\rm tot}$ is independent of W for fixed Q^2. At $W = 220$ GeV, this ratio decreases $\propto \ln(1 + Q^2)$ from 15.8 % at $Q^2 = 4$ GeV^2 to 5.0 % at $Q^2 = 190$ GeV^2.

The diffractive structure function of the proton, $F_2^{\rm D(3)}$ is parametrized in terms of Q^2, the momentum fraction, $x_{I\!P} = (M_X^2 + Q^2)/(W^2 + Q^2)$ of the proton carried by the Pomeron exchanged in the t-channel, and the fraction of the Pomeron momentum carried by the struck quarks, $\beta = Q^2/(M_X^2 + Q^2)$. If $F_2^{\rm D(3)}$ is interpreted in terms of quark densities, it specifies the probability to find, in a proton undergoing a diffractive reaction, a quark carrying a fraction $x = \beta x_{I\!P}$ of the proton momentum. The Q^2 dependence of $x_{I\!P} F_2^{D(3)}$ for fixed β and $x_{I\!P}$ is shown in Fig. 1-(right). The data are dominated by positive scaling violations proportional to $\ln Q^2$ for $x_{I\!P}\beta = x < 1 \cdot 10^{-3}$, while for $x \geq 5 \cdot 10^{-3}$ negative violation is observed. For fixed β, the Q^2 dependence of $x_{I\!P} F_2^{\rm D(3)}$ changes with $x_{I\!P}$. This is inconsistent with the assumption of Regge factorisation, that $x_{I\!P} F_2^{D(3)}(\beta, x_{I\!P}, Q^2)$ factorises into a term that depends only on $x_{I\!P}$ and a second term that depends only on β and Q^2. The comparison with the H1 LRG measurement [2] shows fair agreement for the Q^2 dependence except for a few kinematic regions.

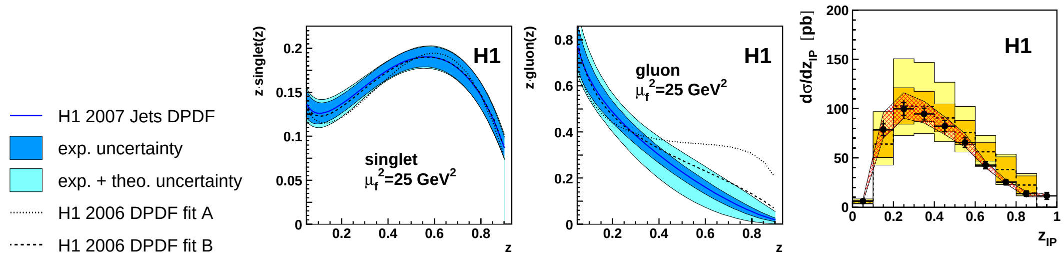

Figure 2: The diffractive quark density (left) and the diffractive gluon density (middle) vs. z for the squared factorisation scale $\mu_f^2 = 25\ \mathrm{GeV}^2$. (right) Differential cross section for diffractive dijets measured by H1 experiment in DIS vs. $z_{I\!P}$ compared to NLO prediction using the H1 2006 DPDF fit B (dashed line). The bands indicate the parton density and hadronisation uncertainties (dark-shaded), and the scale uncertainty (shaded).

3 Diffractive parton densities

In Quantum Chromodynamics (QCD), the diffractive DIS processes can be described by a convolution of universal diffractive parton distributions (DPDFs) and process-dependent coefficients. The DPDFs have been determined through fits to the inclusive diffractive data at HERA using the DGLAP evolution equations. For a parametrisation of the $x_{I\!P}$ dependence of the DPDFs, the proton vertex factorisation is adopted such that the DPDFs are factorised into a term related to the pomeron flux factor depending on $x_{I\!P}$ and t, and a term related to the partonic structure of Pomeron depending on x(or β) and Q^2. In QCD factorisation, next-to-leading order (NLO) QCD calculations based on DPDFs could predict the production rates of more exclusive diffractive processes such as dijet and open charm production.

The DPDFs extracted from H1 LRG measurement [2] with $Q^2 > 8.5\ \mathrm{GeV}^2$, $M_X \geq 2$ GeV and $\beta \leq 0.8$ show that gluons carry ≈ 70 % of the momentum of the diffractive exchange. At large z which is the longitudinal momentum fraction carried by the relevant parton, the diffractive quark density remains well constrained, whereas the sensitivity to the gluon density becomes increasingly poor and the systematic uncertainties also are high. It results from the fact that the results from the gluon density at large z are determined by the inclusive diffractive data at lower z coupled with the chosen parametrisation. The fit (referred to as 'H1 2006 DPDF fit B') was repeated using the different parametrisation of the gluon density. A steeper fall-off in the gluon density at high z is obtained for fit B than for fit A (see Fig. 2-(middle)), while the quark densities agree within the uncertainties (see Fig. 2-(left)).

Dijet production is dominated by the boson-gluon fusion process, where a hard collision of a virtual photon and a gluon produces a high-p_{T} $q\bar{q}$ pair. Therefore, the diffractive dijet data are most directly sensitive to the gluonic content of the diffractive exchange. The prediction based on the H1 2006 DPDF fit B describes the diffractive dijet data in DIS well (see Fig. 2-(right)), while the H1 2006 DPDF fit A shows the overestimation comparing with the data in the region of high $z_{I\!P}$ where $z_{I\!P}$ is the fraction of the momentum of the diffractive exchange carried by the parton entering the hard interaction.

A new set of diffractive parton distribution functions (referred to as 'H1 2007 Jets DPDF') has been obtained through a simultaneous fit to the diffractive inclusive and dijet cross sections [6]. This allows for a precise determination of both the diffractive quark and gluon distributions in the range $0.05 < z_{I\!P} < 0.9$. In particular, the precision on the gluon density at high momentum fraction is improved compared to previous extractions. As shown in Fig. 2-(left) and (right), it is compatible with the H1 2006 DPDF fit B.

The diffractive dijet cross section in DIS agrees well with the QCD predictions, supporting the QCD factorisation for DIS [5,6]. Processes in which a real photon participates directly in the hard scattering are expected to be similar to the DIS of highly virtual photons. By contrast,

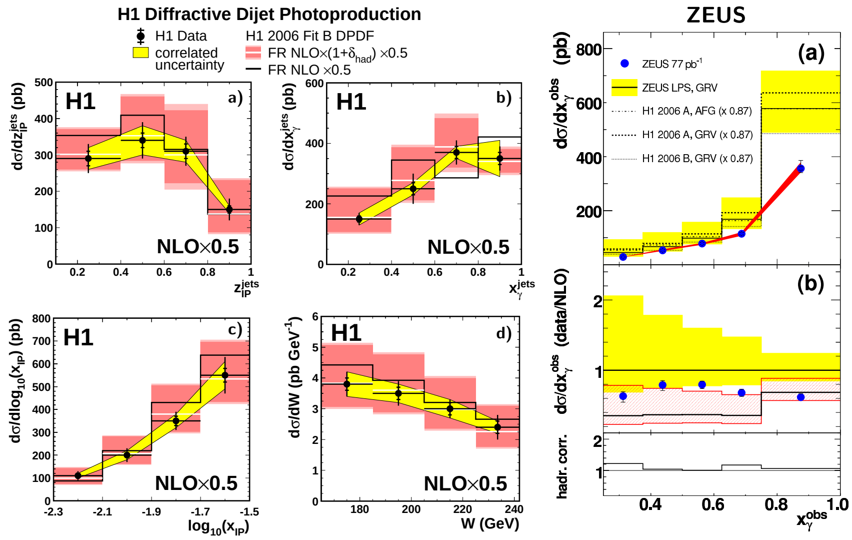

Figure 3: (left) Differential cross sections for diffractive dijets measured by H1 in the photoproduction vs. $z_{I\!P}^{\rm jets}$, $x_\gamma^{\rm jets}$, $\log_{10}(x_{I\!P})$ and W. The NLO prediction from the H1 2006 DPDF fit B scaled by a normalisation factor 0.5 is shown. (right)-(a) Differential cross sections for diffractive dijets measured by ZEUS in the photoproduction vs. $x_\gamma^{\rm obs}$ with NLO QCD predictions. (b) The ratio of the cross sections to the prediction. Note that x_γ is the fraction of the momentum of the photon carried by the parton in the hard scattering.

processes in which the photon is first resolved into partons which then initiate the hard scattering resemble hadron-hadron scattering. Gluon-gluon and gluon-quark final states, which are present in the equivalent $p\bar{p}$ collisions but negligible in DIS, are accessible via resolved photon processes in hard photoproduction. As shown in Fig. 3-(left), NLO calculations based on the H1 2006 DPDF fit B overestimate the measured cross section of H1 diffractive dijets in photoproduction [7]. The ratio of measured cross section to NLO prediction is a factor 0.5 ± 0.1 smaller than the same ratio in DIS, indicating a clear break-down of QCD factorisation. However, Fig. 3-(right) shows that the ZEUS diffractive dijet data in photoproduction [8] are compatible with QCD factorisation within the large uncertainties of the NLO calculations. While the ZEUS dijet events required two jets with a transverse jet energy above $E_T^{\rm jet1\,(2)} > 7.5\ (6.5)$ GeV, the H1 events required two jets with lower E_T like $E_T^{\rm jet1\,(2)} > 5\ (4)$ GeV. Therefore, the E_T distribution of jets may not be well produced by NLO.

Acknowledgments

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