THE POMERON AND VECTOR MESONS AT HERA*

V. Sola

Università di Torino and INFN, Torino, Italy

(Received July 26, 2011)

The H1 and ZEUS Collaborations have measured the inclusive diffractive DIS cross-section $ep \to eXp$ with very high precision across a wide kinematic range. Diffractive parton density functions (DPDFs) have been extracted from the data using the DGLAP evolution equations at next-to-leading-order (NLO) of perturbative QCD. Results from diffractive dijets in DIS have also been included in the fit. Exclusive diffractive vector meson (VM) production and deeply virtual Compton scattering (DVCS) have been studied, shedding light on the transition from the soft to the hard regime of strong interaction.

DOI:10.5506/APhysPolBSupp.4.767
PACS numbers: 13.60.Hb

1. Inclusive diffraction at HERA

Diffractive processes have been studied extensively in deep-inelastic electron–proton scattering (DIS) at the HERA collider. Such interactions are characterised by the presence of a leading proton in the final state carrying most of the initial energy and by the presence of a large gap in rapidity between the proton and the rest of the hadronic system. The kinematic variables used to describe inclusive DIS, $ep \to eX$, are the virtuality of the exchanged photon, Q^2, the Bjorken scaling variable, x, and the inelasticity, y. In addition, the kinematic variables t, $x_{I\!P}$ and β are introduced for diffractive DIS, $ep \to eXp$, with t the squared four-momentum transfer at the proton vertex, $x_{I\!P}$ the longitudinal fractional momentum of the proton carried by the diffractive exchange and β the longitudinal momentum fraction of the struck parton with respect to the diffractive exchange. They are related to x by $x = x_{I\!P}\beta$. The inclusive diffractive DIS cross-section is usually presented in the form of a diffractive reduced cross-section, $\sigma_{\mathrm{r}}^{D(4)}(\beta, Q^2, x_{I\!P}, t)$, related

* Presented at the Workshop "Excited QCD 2011", Les Houches, France, February 20–25, 2011.

to the experimentally measured differential cross-section by

$$\frac{d^4\sigma^{ep\to eXp}}{d\beta dQ^2 dx_{I\!P} dt} = \frac{2\pi\alpha_{em}^2}{\beta Q^2}\left(1 - y - \frac{y^2}{2}\right)\sigma_{\mathrm{r}}^{D(4)}\left(\beta, Q^2, x_{I\!P}, t\right) . \qquad (1)$$

The reduced cross-section $\sigma_{\mathrm{r}}^{D(3)}(\beta, Q^2, x_{I\!P})$ is obtained by integrating $\sigma_{\mathrm{r}}^{D(4)}$ over t.

1.1. Diffractive cross-section measurements

Experimentally, diffractive DIS events can be selected by requiring the presence of a large rapidity gap (LRG). A complementary way is the direct measurement of the outgoing proton by using Proton Spectrometers (PS). Whilst the LRG-based technique yield better statistics than the PS method, it suffers from systematic uncertainties associated with background events due to proton dissociation.

The H1 Collaboration recently published a proton-tagged measurement using its full available sample of Forward Proton Spectrometer (FPS) data at HERA-II [1]. The measurement considerably improves the statistical uncertainty and the kinematical coverage with respect to the previous H1 FPS results from HERA-I [2], being based on a factor 20 more integrated

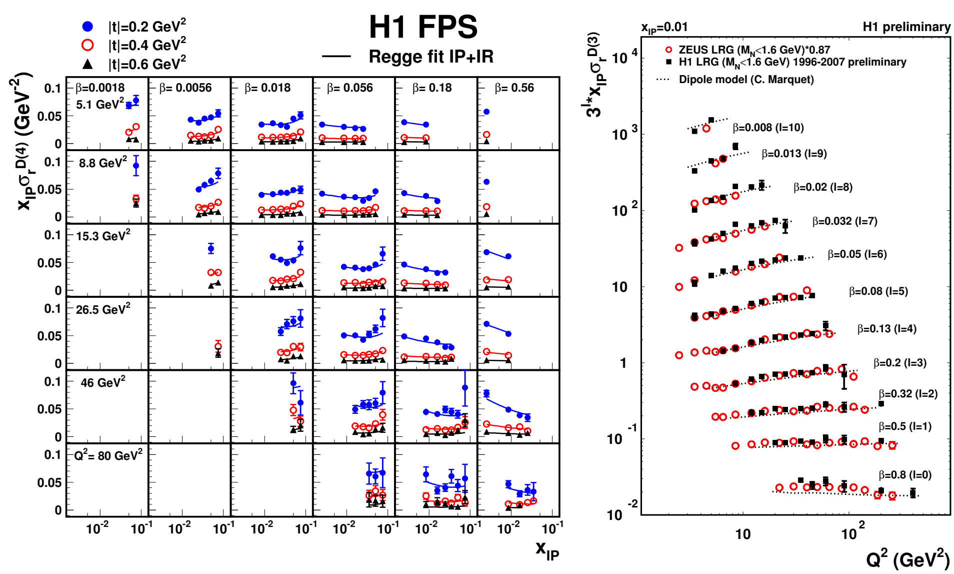

Fig. 1. Left: The H1 FPS measurement of $x_{I\!P}\sigma_{\mathrm{r}}^{D(4)}(\beta, Q^2, x_{I\!P}, t)$ as a function of $x_{I\!P}$. Right: Comparison between the H1 and ZEUS LRG measurements of $x_{I\!P}\sigma_{\mathrm{r}}^{D(3)}(\beta, Q^2, x_{I\!P})$ as a function of Q^2 (right).

luminosity. As shown in figure 1 (left), the new data allow to measure the reduced diffractive cross-section $\sigma_r^{D(4)}$ in 3 different bins of t, covering the range $0.1 < |t| < 0.7$ GeV^2.

The H1 Collaboration also released preliminary results of the reduced diffractive cross-section $\sigma_r^{D(3)}$ obtained as the combination of all the measurements performed by the Collaboration with data collected from 1996 to 2007 and selected with the LRG technique [3]. The preliminary cross-sections are shown in figure 1 (right), compared to the last published ZEUS results [4]. Good agreement is observed between the shapes of the H1 and ZEUS cross-sections throughout most of the phase space studied. An average 13% normalization difference between the two experiments has been estimated.

1.2. Diffractive parton density functions

It has been shown by Collins [5] that the diffractive DIS process $ep \to eXp$ factorises into diffractive parton density functions (DPDFs) times a term related to the hard-scattering partonic cross-section; a useful additional assumption (proton vertex factorisation) is often made whereby the proton vertex dynamics factorises from the vertex of the hard scatter. The β and Q^2 dependences of $\sigma_r^{D(3)}$ may then be subjected to a perturbative QCD analysis based on the DGLAP equations, in order to obtain diffractive PDFs. Whilst F_2^D directly measures the quark density, the gluon density is only indirectly constrained by scaling violations, $\partial F_2^D/\partial \ln Q^2$.

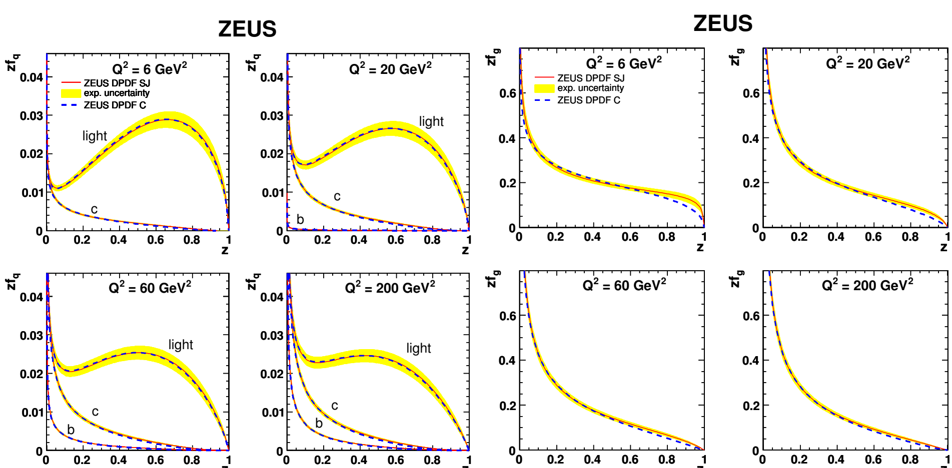

Fig. 2. ZEUS singlet (left) and gluon (right) densities as a function of the momentum fraction, z, for four different values of Q^2. The shaded error bands represent the experimental uncertainty.

The high statistics ZEUS LRG and LPS data [4] have recently been fitted to extract DPDFs [6]. The method and DPDF parametrisations are similar to a previous H1 analysis [7], the main difference being in the heavy flavour treatment, which in the ZEUS case follows the general-mass variable-flavour-number scheme. In the resulting DPDFs the quark densities are relatively well known throughout the phase space, whilst the uncertainties on the gluon density are large, in particular at high fractional momentum, z. Indeed, in this region the dominant parton splitting is $q \to qg$ and the sensitivity of $\partial F_2^D/\partial \ln Q^2$ to the gluon density becomes poor. A better constraint at large z has been obtained by including in the fit diffractive dijet production data [8], which are directly sensitive to gluons via the boson–gluon fusion process. The resulting quark and gluon densities are presented in figure 2, showing a comparable precision across the whole z range.

2. Exclusive vector meson production

Exclusive electroproduction of vector mesons is a particularly good process for studying the transition from the soft to the hard regime of strong interactions, the former being well described within the Regge phenomenology [9] while the latter by perturbative QCD (pQCD). Two of the most striking expectations in this transition are the change of the logarithmic derivative δ of the cross-section with respect to the (virtual) photon–proton centre-of-mass energy W, from a value of about 0.2 in the soft regime to 0.8 in the hard one, and the decrease of the exponential slope b of the differential cross-section with respect to t, from a value of about 10 GeV^{-2} to an asymptotic value of about 5 GeV^{-2} when the virtuality Q^2 of the exchanged photon increases.

2.1. W dependence of the cross-section

The soft to hard transition can be seen by studying the W dependence of the cross-section for exclusive photoproduction of vector mesons, from the lightest one, ρ^0, to the heavier ones, up to the Υ. The scale is the mass of the vector meson, as in photoproduction $Q^2 = 0$. Figure 3 (left) shows $\sigma(\gamma p \to VMp)$ as a function of W for light and heavy vector mesons. For comparison, the total photoproduction cross-section, $\sigma_{\rm tot}(\gamma p)$, is also shown. The data can be parametrized as W^δ, and the value of δ is displayed in the figure for each process. One clearly sees the transition from a shallow W dependence to a steeper one as the scale increases.

This transition can also be studied by varying Q^2 for a given vector meson. The cross-section $\sigma(\gamma^* p \to \rho^0 p)$ [10] is presented in figure 3 (right) as a function of W, for different values of Q^2. The cross-section rises with

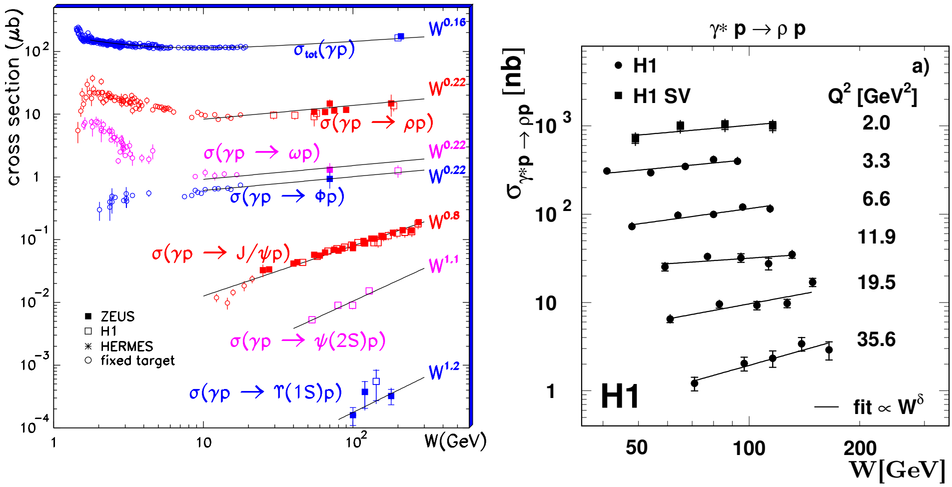

Fig. 3. Left: The W dependence of the cross-section for exclusive vector meson photoproduction . Right: The W dependence of the cross-section for exclusive ρ^0 electroproduction, for different Q^2 values.

W in all Q^2 bins. In order to quantify this rise, the parameter δ is obtained by fitting the data as W^δ in each of the Q^2 intervals.

The resulting values of δ from the HERA measurements are compiled in figure 4 (left). The results are plotted as a function of the combined scale Q^2+M^2, where M is the mass of the vector meson. A universal behaviour is observed, showing an increase of δ as the scale becomes larger, in agreement with the expectations.

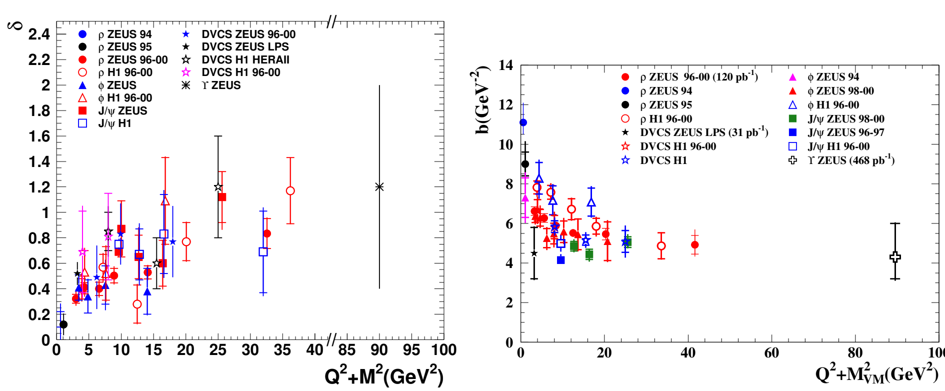

Fig. 4. A compilation of the values of δ from a fit of the form $\sigma \sim W^\delta$ (left) and of the slope b from a fit of the form $d\sigma/d|t| \sim e^{-b|t|}$ (right) for exclusive VM electroproduction, as a function of $Q^2 + M^2$. DVCS results are also included.

2.2. t dependence of the cross-section

The differential cross-section $d\sigma/dt$ has been parametrised as an exponential function $e^{-|t|b}$ and fitted to the data of exclusive vector meson electroproduction and also of DVCS. The resulting values of b as a function of the scale $Q^2 + M^2$ are plotted in figure 4 (right). As expected, b decreases to a universal value of about 5 GeV^{-2} as the scale increases.

The value of b can be related via a Fourier transform to the impact parameter. Assuming that the process of exclusive electroproduction of vector mesons is hard and dominated by gluons, one can use the relation $\langle r^2 \rangle = b(\hbar c)^2$ to obtain the radius of the gluon density in the proton. The value of about 5 GeV^{-2} corresponds to a value of $\langle r \rangle_g \sim 0.6$ fm, smaller than the value of the charge density radius of the proton ($\langle r \rangle_p \sim 0.8$ fm), indicating that the gluon is well constrained within the charge-radius of the proton.

3. Conclusions

The H1 and ZEUS collaborations are finalising measurements of the inclusive diffractive DIS cross-section, $ep \to eXp$, with the full statistics available from HERA. The DPDFs extracted from NLO QCD fits to inclusive and dijets data result in quark and gluon densities constrained with good precision across the whole kinematic range. A compilation of the latest HERA results on exclusive vector meson electroproduction allows to observe the transition from the soft to the hard regime of strong interactions.

REFERENCES

[1] [H1 Collaboration], F.D. Aaron *et al.*, *Eur. Phys. J.* **C71**, 1578 (2011).
[2] [H1 Collaboration], A. Aktas *et al.*, *Eur. Phys. J.* **C48**, 749 (2006).
[3] H1 Collaboration, F2D3 with rapidity gap, [H1prelim-10-011].
[4] [ZEUS Collaboration], S. Chekanov *et al.*, *Nucl. Phys.* **B816**, 1 (2009).
[5] J.C. Collins, *Phys. Rev.* **D57**, 3051 (1998) [*Erratum ibid.* **D61**, 019902(E) (1999)].
[6] [ZEUS Collaboration], S. Chekanov *et al.*, *Nucl. Phys.* **B831**, 1 (2010).
[7] [H1 Collaboration], A. Aktas *et al.*, *Eur. Phys. J.* **C48**, 715 (2006).
[8] [ZEUS Collaboration], S. Chekanov *et al.*, *Eur. Phys. J.* **C52**, 813 (2007).
[9] T. Regge, *Nuovo Cim.* **14**, 951 (1959); *Nuovo Cim.* **18**, 947 (1960).
[10] [H1 Collaboration], F.D. Aaron *et al.*, *J. High Energy Phys.* **05**, 32 (2010).