Diffraction at HERA [1]

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Abstract. Recent measurements of inclusive processes, vector meson production and hadronic final states in diffractive interactions at HERA are presented. The data are used to investigate the factorization properties and study the partonic structure of colour singlet exchange.

INTRODUCTION

In its first running period, which ended in 2000, the ep collider HERA delivered more than $100pb^{-1}$ of integrated luminosity for each of the two experiments H1 and ZEUS. In this report we present some recent results on diffractive physics.

The diffractive dissociation of the photon $\gamma p \to Xp$ has characteristics similar to diffractive hadron–hadron interactions and can be described by Regge phenomenology. Within this framework, diffractive interactions at high energies are dominated by the exchange of the Pomeron, an object with vacuum quantum numbers. On the other hand, perturbative QCD (pQCD) calculations can be made for diffractive processes in which a hard scale is present: processes with high virtuality Q^2 or high four-momentum transfer squared $|t|$, or processes where the high p_T jets or heavy quarks are produced. In pQCD, the vacuum exchange can be modelled as the exchange of a colour singlet gluon ladder between the proton and the virtual photon, which fluctuates into a $q\bar{q}$ or $q\bar{q}g$ state before the interaction [1]. In this approach, the cross section is factorized into the square of the effective dipole wave function and the square of the cross section for diffractive scattering of the dipole off the proton.

At HERA, it is possible to vary the scale with which the Pomeron structure is probed in diffractive interactions, to study its partonic content and the transition from soft to hard interactions.

DIFFRACTIVE VECTOR MESON PRODUCTION

Vector meson production has been extensively studied at HERA both in the photoproduction ($Q^2 \sim 0$) and DIS regimes ($Q^2 > 1\ GeV^2$). Figure 1 presents the exclusive pho-

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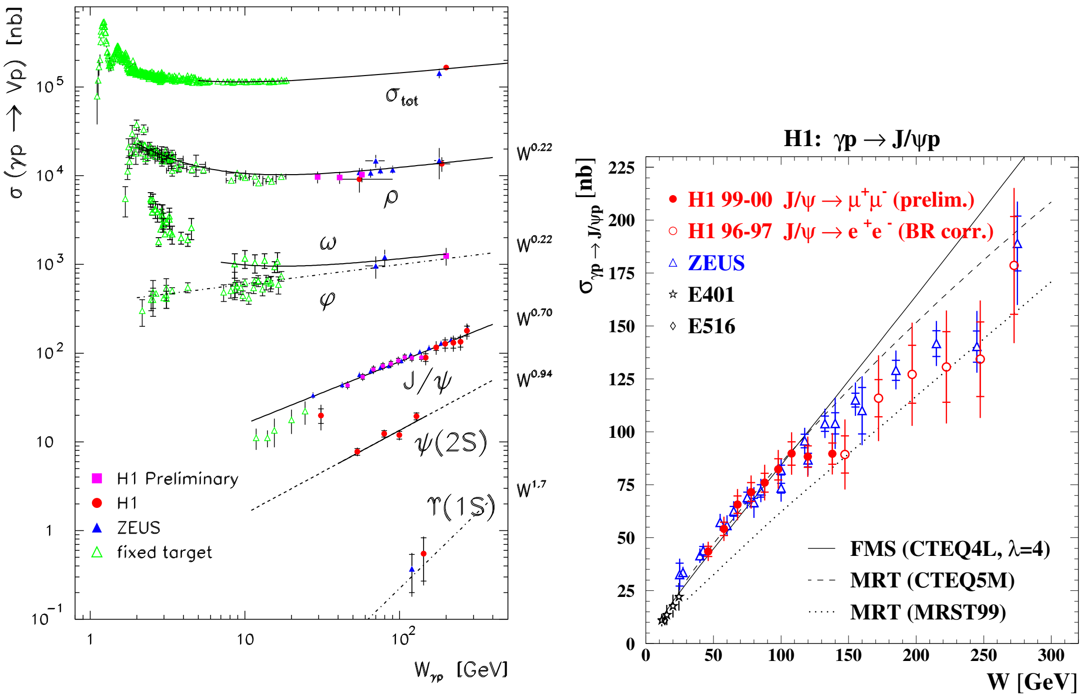

FIGURE 1. **a)** Vector meson cross sections as a function of the total CM energy of the photon-proton system $W_{\gamma p}$ in photoproduction ($Q^2 = 0$); **b)** The J/ψ meson cross section as a function of $W_{\gamma p}$ in photoproduction ($Q^2 = 0$) compared with pQCD calculations.

toproduction cross section for different vector mesons as a function of the γp center of mass energy, $W_{\gamma p}$ [2, 3]. The cross sections for light vector mesons (ρ, ω, ϕ) follow the soft behaviour of the total photon–proton cross section parameterized as $\sim W^{0.2}$ in agreement with the predictions of the Regge approach [4]. In contrast, the J/ψ cross section exhibits much harder energy dependence ($\sim W^{0.8}$) [5, 6]. Here, the mass of the charm quark sets the hard scale for pQCD calculations, and the steep energy dependence, which is related to the rise of the gluon density in the proton at small values of Bjorken-x, is quite well described by pQCD predictions [7].

Figure 2 shows the ρ cross section for different values of Q^2 as a function of W [8]. The energy dependence of the cross section becomes steeper as Q^2 increases. For light vector mesons, Q^2 plays the role of the hard scale, similar to the mass of the charm quark in the case of J/ψ photoproduction.

INCLUSIVE DIFFRACTION IN DIS

The kinematics of diffractive deep inelastic scattering, $ep \to eXp$, can be expressed in terms of the photon virtuality Q^2, the squared four momentum transfer t, Bjorken x, the fraction of the beam proton's momentum carried by the Pomeron, $x_{I\!P}$, and the fraction of the Pomeron's momentum carried by the struck quark, β. The cross section for the

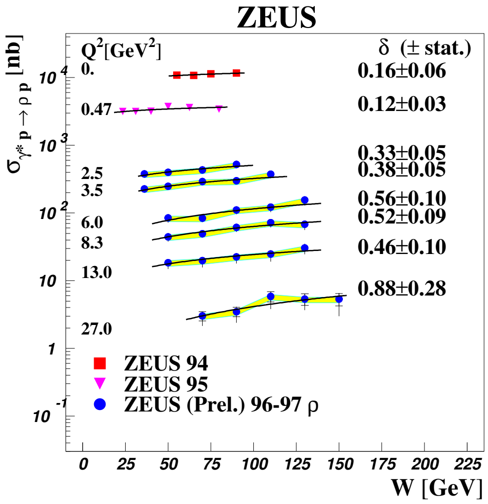

FIGURE 2. The ρ meson cross section as function of $W_{\gamma p}$ at different values of Q^2.

diffractive DIS process can be described by an expression analogous to that used for inclusive DIS:

$$\frac{d\sigma^D}{d\beta dQ^2 dx_{I\!P}} = \frac{2\pi\alpha}{\beta Q^4}(1-y+\frac{y^2}{2})(F_2^D - \frac{y^2}{1+(1-y)^2}F_L^D),$$

In Fig.3 the new high-precision H1 and ZEUS measurements of diffractive structure function are shown as a function of $x_{I\!P}$ for different Q^2 and β bins [9, 10]. The H1 measurements are used in a DGLAP QCD analysis in order to extract diffractive parton densities. These parton densities are universal for diffractive DIS processes [11]. In addition, Regge factorization between the $(x_{I\!P}, t)$ and (x, Q^2) dependences is assumed, according to which the Pomeron PDF is independent of $x_{I\!P}$ and t.

The extracted NLO singlet quark $\Sigma(z, Q^2)$ and gluon densities $g(z, Q^2)$, together with their uncertainties, are shown in Fig.4 [10]. Here the variable z corresponds to the momentum fraction carried by an individual parton. The comparison of quark and gluon contributions shows that up to 75% of the Pomeron's momentum is carried by gluons. It is also apparent that due to the indirect extraction of $g(z, Q^2)$ from the scaling violation, the gluon densities at high z have large uncertainties.

DIFFRACTIVE DIJET AND CHARM PRODUCTION

According to the QCD factorization theorem [11], the parton distribution functions extracted from the QCD fits to diffractive structure functions can be used to describe hadronic final states in diffractive DIS. Of particular interest are measurements of open charm, $\gamma^* q \rightarrow c\bar{c}$, and diffractive dijet production since the boson–gluon fusion process provides a direct probe of the gluon content of the Pomeron, in contrast to inclusive measurements. The presence of a hard scale provided by the high transverse momentum of the jets or the mass of the charm quark allows the testing of different QCD based models.

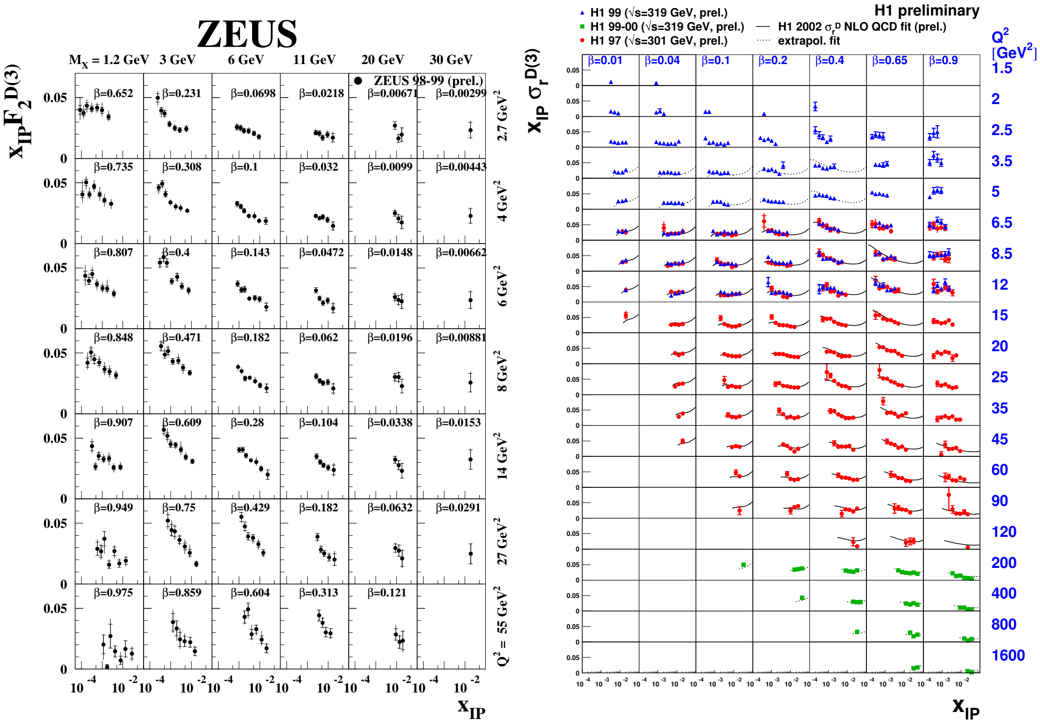

FIGURE 3. Diffractive structure function F_2^D and the reduced cross section $\sigma_R^D \equiv F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D$ as a function of $x_{I\!P}$ for fixed β and Q^2.

Figure 5 shows the cross sections for diffractive dijet and diffractive D^* meson production in DIS as a function of $z_{I\!P}$, which represents the longitudinal momentum fraction of the diffractive exchange entering the hard scattering [12]. These measurements are compared with LO and NLO calculations using the DISENT [13] and HVQDIS [14] programs which use PDFs extracted from inclusive diffractive DIS data. The NLO calculations, corrected for hadronization effects, provide within the theoretical and experimental uncertainties a reasonable description of the shape and normalization of the measured cross section. The results are thus consistent with QCD factorization in diffractive DIS.

Dijet production in diffractive interactions was also studied in the photoproduction regime [15]. Here, the resolved and direct processes are distinguished by reconstructing the variable x_γ, defined as the fractional momentum of the quasi-real photon entering the dijet system. For direct processes $x_\gamma = 1$, while in the case of resolved processes $x_\gamma < 1$ will hold. Figure 6 displays the measured cross sections for diffractive dijet photoproduction as a function of x_γ^{jet} together with the prediction based on the diffractive parton densities from the QCD fit. The sum of resolved and direct processes in the model gives a good description of the data both in normalisation and in shape throughout the x_γ^{jet} range.

In contrast to this result, a large discrepancy was observed between the predictions and the measurements made by the CDF collaboration in the process $p\bar{p} \to pX$ at $\sqrt{s} = 1800\ GeV$ [16, 10]. The overestimation of the measured cross section by a factor

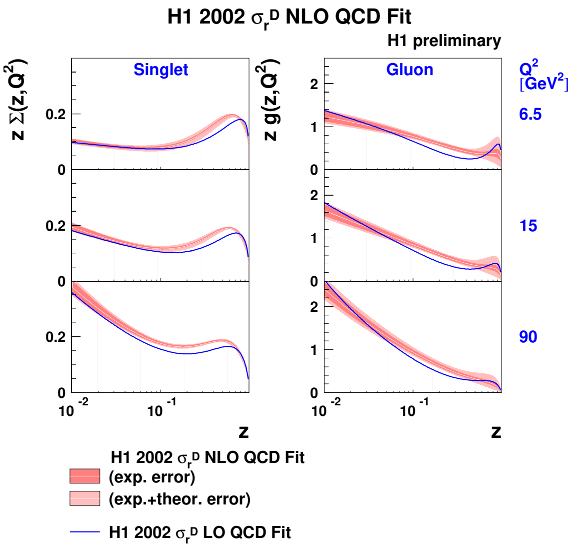

FIGURE 4. Pomeron parton densities. The left hand side shows the singlet quark distribution, the right hand side shows the gluon density.

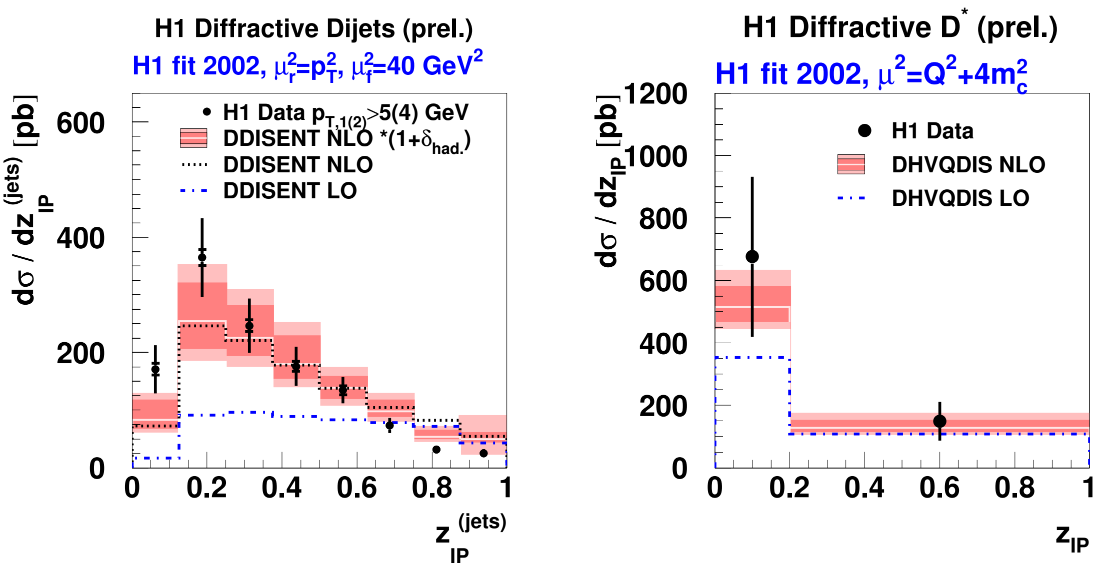

FIGURE 5. Diffractive dijet and diffractive D^* production cross sections compared with the DISENT and HVQDIS calculations.

of 5–10 indicates a breakdown of factorization. This has often been interpreted as being due to additional spectator interactions which lead to the suppression of the diffractive cross section. There is however no evidence for any suppression of the diffractive cross section in the H1 data in the region dominated by resolved photons, as might be expected on the basis of the CDF measurements.

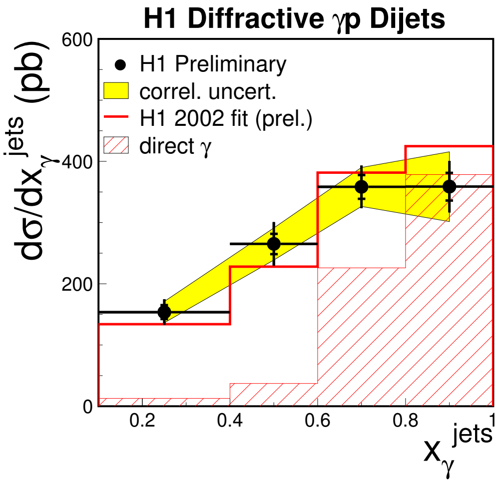

FIGURE 6. Diffractive dijet cross section in photoproduction compared with predictions using the QCD fits to diffractive DIS data.

CONCLUSIONS

HERA is an ideal facility for the study of the transition from soft to hard diffraction, explored using different hard scales ($Q^2, M_q, p_T^{jet}, \ldots$).

The measurements of inclusive diffraction and the hadronic final state in diffractive DIS can be described within a consistent picture. The results support QCD factorization with diffractive parton densities which are evolved according to the DGLAP equations and are dominated by the gluonic contribution.

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