DIFFRACTION AT HERA

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At the electron-proton collider HERA, diffractive interactions represent $\sim 10\%$ of the deep inelastic scattering. The production of diffractive events, characterised by the presence of a gap in rapidity or angular region without particle production, can be explained in the framework of the Regge model by the exchange of a colorless object, named the Pomeron. Describing the nature of the pomeron is a challenge for Quantum Chromodynamics. Results from the H1 and ZEUS Collaborations on exclusive vector meson production and on inclusive diffractive processes are presented.

1 Introduction

HERA is a high energy electron-proton collider, the beam energies being 27.5 GeV and 820 GeV (or 920 GeV after 1999, depending on the year of data taking). One of the aims of the H1 and ZEUS Collaborations is the study of the proton structure in ep collisions. Figure 1a presents a sketch of the deep inelastic scattering (DIS) $ep \to eX$ reaction. The electron emits a photon of four momentum q and virtuality $Q^2 = -q^2$, which collides with a quark in the proton. A color string connects the struck quark and the proton remnant, leading to gluon radiation and particle emission, and thus forming the hadronic system X.

In $\sim 10\%$ of the DIS events, a particular topology is observed [1]: a large rapidity gap without particle emission is found between the hadronic system X of mass M_X and the scattered proton which remains intact or breaks up into a low mass system Y (see fig. 1b). Such events are diffractive: the photon fluctuates into a $q\bar{q}$ pair which interacts with the proton through the exchange of a pomeron, a colorless object carrying the vacuum quantum numbers. No color flow occurs thus between the proton and the hadronic system X resulting from the diffractive dissociation of the photon.

Diffractive interactions were previously studied in hadron-hadron interactions and are well described by Regge phenomenology. They can be viewed as a generalisation of elastic scattering and are thus related to the total cross section through the optical theorem. The energy dependence of the total hadron-hadron cross section is characterised, at high energy, by a slow ("soft") rise attributed to pomeron exchange. A mechanism is however needed to damp

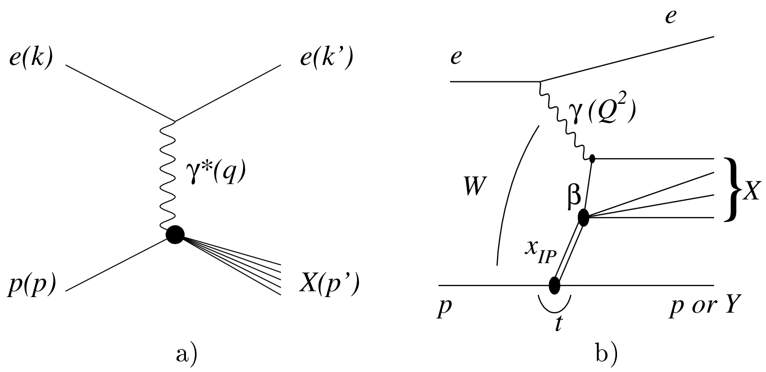


Figure 1. Sketches of a) the deep inelastic scattering $ep \to eX$ reaction and b) the diffractive $ep \to eXp$ interaction.

this increase at very high energy, to preserve the unitarity of the S-matrix.

It is a challenge for Quantum Chromodynamics (QCD) to provide a microscopic picture of the pomeron, in terms of quarks and gluons. The large kinematical range in Q^2 accessible at HERA allows the detailled study of the diffractive mechanism from soft to hard regime. For this reason, HERA is a unique laboratory to study the pomeron in QCD.

2 Diffractive vector meson production

Vector meson (VM) production, both in photo- ($Q^2 \simeq 0$ GeV^2) and electroproduction ($Q^2 \geq 1$ GeV^2), has been intensively studied at HERA for ρ, ω, ϕ, J/Ψ, ... The system X consists only of the vector meson, which is detected through its decay products. This very clean process is calculable in perturbative QCD (pQCD) if a hard scale is provided, e.g. sufficiently high Q^2 or a heavy quark mass. At lowest order, the pomeron exchange can be modelled by two gluons (see fig. 2). The cross section is then proportional to the square of the gluon density in the proton [2].

Figure 3a presents the exclusive cross section for different vector mesons at $Q^2 \simeq 0$ GeV^2 as a function of the γp centre of mass energy W. The cross sections for light vector mesons (ρ, ω, ϕ) [3,4] follow the soft behaviour of the total hadron-hadron cross section parametrised as $\sim W^{0.2}$. In contrast, the J/Ψ cross section [5] exhibits a strong ("hard") dependence ($\sim W^{0.8}$) described

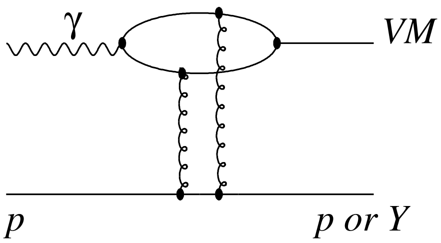


Figure 2. Exclusive vector meson production

by pQCD. This hard dependence is related to the rise of the gluons observed in F_2 at small values of the Bjorken variable x [6] ($W^2 \simeq Q^2/x$).

Figure 3b shows the ρ cross section [7] for different values of Q^2 as a function of W, fitted as $\propto W^{\delta}$. As Q^2 increases, the cross section leaves the soft dependence typical of hadron-hadron interactions and progressively reaches the hard behaviour predicted by pQCD. In this case, Q^2 plays the role of the hard scale, similar to the mass of the c quark for J/Ψ photoproduction.

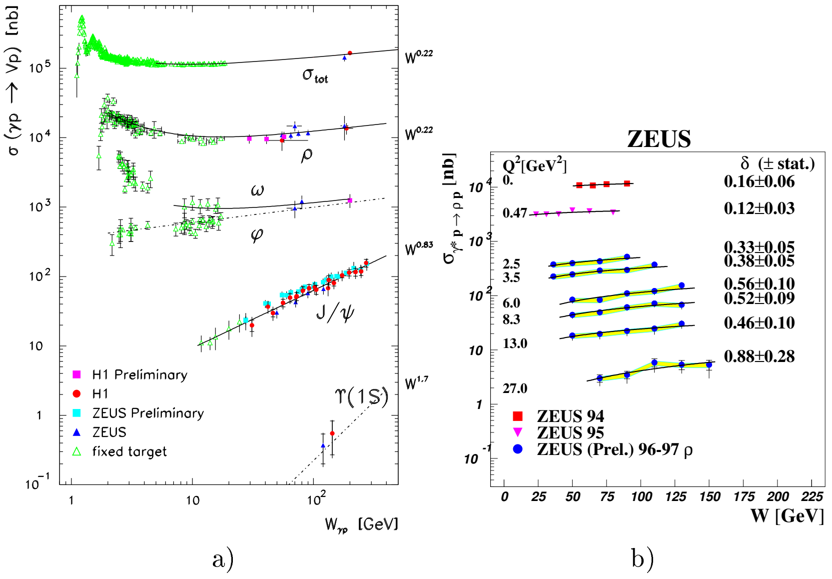


Figure 3. a) Vector meson cross section as a function of W at $Q^2 = 0$ GeV^2, b) ρ cross section as a function of W in the DIS domain for different Q^2 values.

3 The diffractive structure function F_2^D

In a way similar to the proton structure F_2 in inclusive DIS, the diffractive structure function F_2^D is studied at HERA in the $ep \to eXp$ reaction where the proton stays intact. F_2^D is given by the relation:

$$\frac{d^3\sigma_{ep\to eXp}}{d\beta\ dQ^2\ dx_{I\!P}} = \frac{4\pi\alpha^2}{\beta\ Q^4}\ (1-y+\frac{y^2}{2})\ F_2^{D(3)}(\beta, Q^2, x_{I\!P}) \tag{1}$$

where α is the electromagnetic constant and y is the usual scaling variable $y \simeq W^2/s$ ($\sqrt{s}$ being the ep centre of mass energy). $x_{I\!P}$ and β are

$$x_{I\!P} = \frac{-q\cdot k}{q\cdot p} \simeq \frac{Q^2+{M_X}^2}{Q^2+W^2} \text{ and } \beta = \frac{-\mathrm{Q}^2}{2\mathrm{q}\cdot\mathrm{k}} \simeq \frac{\mathrm{Q}^2}{\mathrm{Q}^2+{\mathrm{M_X}}^2}, \tag{2}$$

k and p being respectively the four momentum of the initial electron and proton. In the infinite proton momentum frame, $x_{I\!P}$ can be interpreted as the proton momentum fraction carried by the pomeron and β as the pomeron momentum fraction carried by the quark probed by the photon.

A factorisation theorem has been proven for this process [8]:

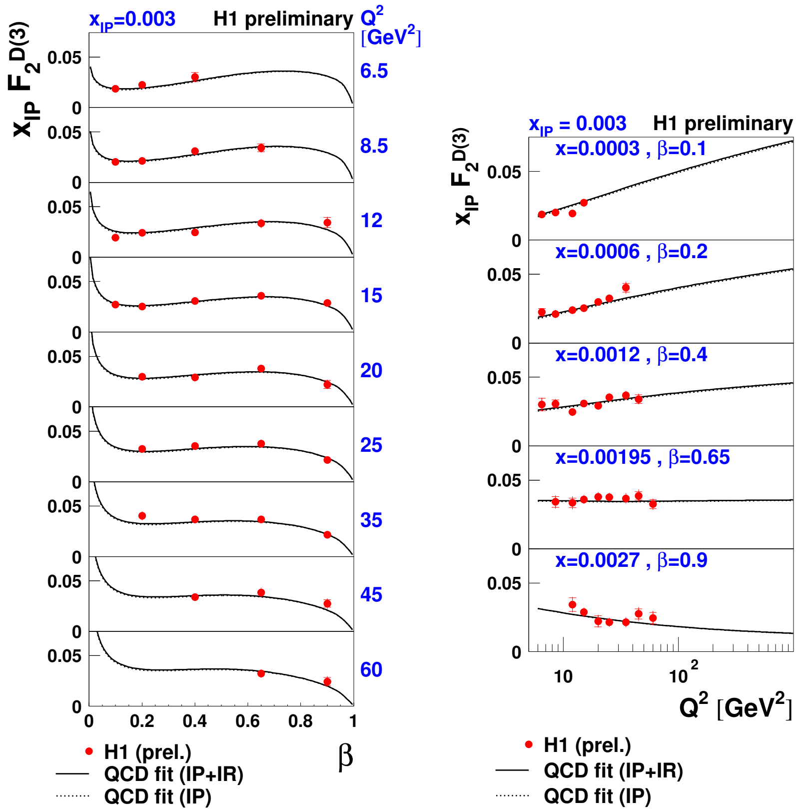
$$\sigma(\gamma^* p \to Xp) \propto \sum_i f_{i/p}(x_{I\!P}, t, x, Q^2) \times \sigma_{\gamma^* i}(x, Q^2) \tag{3}$$

where $f_{i/p}$ are the diffractive parton density functions and $\sigma_{\gamma^* i}$ the hard scattering coefficients.

Figure 4 presents the dependence of $x_{I\!P}\ F_2^{D(3)}$ at fixed $x_{I\!P}$ as a function of a) β for different Q^2 values and b) Q^2 for different β values [9]. A strong scaling violation is observed up to relatively large β. This is an indication for a dominant gluonic component of the pomeron. A QCD fit, performed on the data using the DGLAP evolution equations, describes the evolutions in β and Q^2 well. It shows that gluons carry up to 80 % of the momentum of the pomeron [10].

At HERA, the diffractive parton density functions are used to predict the cross sections for several exclusive or semi-inclusive diffractive processes [a], for example, the production of dijets [12], which supports the gluonic structure of the pomeron.

[a] This is however not possible at the Tevatron [11] where the rapidity gap, characteristic of diffraction, is in some fraction of the events destroyed by underlying interactions between the beam particles (concept of gap survival probability).



a) b)

Figure 4. Evolution of $x_{I\!P} F_2^{D(3)}$ at fixed $x_{I\!P}$, as a function of a) β for different Q^2 values and b) Q^2 for different β values.

4 Conclusions

At HERA, $\sim$ 10% of the events in the DIS domain show a large rapidity gap. They are classified as diffractive events and can be explained by the exchange of a pomeron. The analysis of the scaling violations in the diffractive structure function has shown a mostly gluonic nature of the pomeron. The results concerning diffractive final states support this idea. With vector meson production, the transition from soft to hard diffraction can be explored using different hard scales (Q^2, M_q, ...). This makes of HERA a unique tool to study diffraction.

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References

1. M. Derrick *et al.* [ZEUS Collaboration], *Phys. Lett.* B **315**, 481 (1993); T. Ahmed *et al.* [H1 Collaboration], *Nucl. Phys.* B **429**, 477 (1994).
2. M. G. Ryskin, *Z. Phys.* C **57**, 89 (1993); S. J. Brodsky et al., *Phys. Rev.* D **50**, 3134 (1994) [hep-ex/9402283].
3. C. Adloff *et al.* [H1 Collaboration], paper (♯ 810) subm. to the conf. EPS2001, paper (♯ 795) subm. to the conf. EPS2001.
4. J. Breitweg *et al.* [ZEUS Collaboration], *Eur. Phys. J.* C **2**, 247 (1998) [hep-ex/9712020], M. Derrick *et al.* [ZEUS Collaboration], *Z. Phys.* C **73**, 73 (1996) [hep-ex/9608010], *Phys. Lett.* B **377**, 259 (1996) [hep-ex/9601009]
5. J. Breitweg *et al.* [ZEUS Collaboration], paper (♯ 5480) subm. to the conf. EPS2001; C. Adloff *et al.* [H1 Collaboration], *Phys. Lett.* B **483**, 23 (2000) [hep-ex/0003020].
6. C. Adloff *et al.* [H1 Collaboration], *Nucl. Phys.* B **497**, 3 (1997) [hep-ex/9703012]; J. Breitweg *et al.* [ZEUS Collaboration], *Phys. Lett.* B **487**, 53 (2000) [hep-ex/0005018].
7. J. Breitweg *et al.* [ZEUS Collaboration], paper (♯ 594) subm. to the conf. EPS2001, C. Adloff *et al.* [H1 Collaboration], *Eur. Phys. J.* C **13**, 371 (2000) [hep-ex/9902019].
8. J. C. Collins, *Phys. Rev.* D **57**, 3051 (1998) [Erratum-ibid. D **61** (1998) 019902] [hep-ph/9709499].
9. C. Adloff *et al.* [H1 Collaboration], paper (♯ 808) subm. to the conf. EPS2001
10. C. Adloff *et al.* [H1 Collaboration], *Z. Phys.* C **76**, 613 (1997) [hep-ex/9708016].
11. T. Affolder *et al.* [CDF Collaboration], *Phys. Rev. Lett.* **84**, 5043 (2000).
12. C. Adloff *et al.* [H1 Collaboration], *Eur. Phys. J.* C **20**, 29 (2001) [hep-ex/0012051].