HARD DIFFRACTION IN VECTOR MESON PRODUCTION AT HERA

On behalf of the H1 and ZEUS Collaborations

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Results on elastic vector meson production at HERA are presented in the framework of perturbative QCD. The energy dependence of the cross section for J/ψ photoproduction and for ρ electroproduction is studied. A full polarisation analysis, including the measurement of the 15 elements of the spin density matrix and of $R = \sigma_L/\sigma_T$, is presented for ρ electroproduction. Finally heavier vector mesons (ψ' and Υ) production is discussed.

1 Introduction

Elastic electroproduction of vector mesons, $e + p \rightarrow e + p + V$, is studied at HERA [1,2,3,4,5] in a wide kinematical range in Q^2 (the photon virtuality), W (the $\gamma^{(*)}p$ centre of mass energy), t (the square of the 4-momentum exchanged at the proton vertex) and m_V (the vector meson mass) (see Fig. 1a). The vector mesons $V = \rho, \omega, \phi, J/\psi, \psi'$ and Υ have the same quantum numbers as the photon ($J^{PC} = 1^{--}$) and the $\gamma^{(*)}p$ interaction is mediated by the exchange of a colourless object, the pomeron. Pomeron exchange was studied in detail in the framework of the Regge model; interest is now to understand it in terms of partons in the framework of the QCD theory. An important result of HERA studies is that, in contrast to the slow increase with the energy of the hadron-hadron cross sections ("soft" behaviour), the total $\gamma^* p$ cross section has a strong ("hard") energy dependence, which is attributed to a fast rise with energy of the gluon density in the proton. The QCD pomeron being described as a gluonic system, a "hard" behaviour is thus also expected in vector meson production.

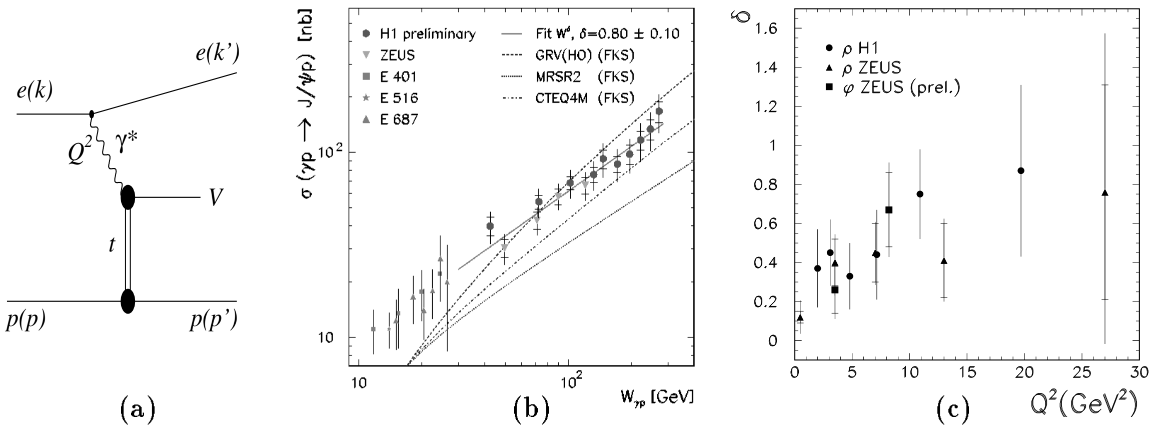

Figure 1: a) Diagram for the reaction $e + p \to e + p + V$; b) Cross section $\sigma(\gamma p \to J/\psi p)$ for J/ψ meson photoproduction as a function of W. The dotted lines represent predictions of a perturbative QCD model [7] using different gluon density parametrisations and the solid line represents a fit to the data using the parametrisation $\sigma \propto W^\delta$, with $\delta = 0.80 \pm 0.10$; c) Q^2 dependence of the δ parameter for ρ and ϕ electroproduction.

2 Vector meson production in pQCD

Quantitative predictions in perturbative QCD are possible when a hard scale is present in the interaction. This scale can be given by Q^2, $|t|$ or m_q, the quark mass. Most models rely on the fact that, at high energy, in the proton rest frame, the photon fluctuates into a $q\bar{q}$ pair a long time before the interaction, and recombines into a vector meson (VM) a long time after the interaction. The amplitude $\mathcal{M}$ then factories in three terms: $\mathcal{M} \propto \psi^{V\,*}_{\lambda_V}\ T_{\lambda_V\lambda_\gamma}\ \psi^{\gamma}_{\lambda_\gamma}$ where $T_{\lambda_V\lambda_\gamma}$ are the interaction helicity amplitudes (λ_γ and λ_V being the helicities of the photon and the VM respectively) and ψ represents the wave functions. In most models, the $q\bar{q} - p$ interaction is described by a 2 gluon exchange. The cross section is then proportional to the square of the gluon density in the proton: $\sigma_{\gamma p} \sim \alpha_s^2(Q^2)/Q^6 \cdot \left|xg(x,Q^2)\right|^2$. The main uncertainties of the models come from the choice of the scale, of the gluon distribution parametrisation, of the VM wave function (Fermi motion), and from the neglect of off-diagonal gluon distributions and of higher order corrections.

3 Energy dependence of the cross sections

At high energy, the total, elastic, and diffractive cross sections are dominated by pomeron exchange and the energy dependence of the cross sections exhibits the “soft” behaviour, parametrised as $\sigma \propto W^\delta$, with $\delta = 0.22$. The ρ, ω and ϕ photoproduction cross sections measured by the fixed target experiments and at HERA present the same “soft” dependence. However the J/ψ photoproduction cross section, where the mass of the c quark provides a hard scale in the interaction, presents a much stronger energy dependence (“hard” behaviour)[6], in agreement with the rise of the gluon density at low x ($x \simeq Q^2/\ W^2$). Figure 1b presents the HERA measurement together with predictions of a perturbative QCD model [7] using three parametrisations for the gluon density: GRVHO, MRSR2 and CTEQ4M. The full line represents a fit to the data using the parametrisation $\sigma \propto W^\delta$ with $\delta = 0.8 \pm 0.1$. This value of δ is in contrast with the value $\delta = 0.22$ obtained for the “soft” energy dependence of light vector mesons photoproduction.

Another way to look at hard behaviour is to study light vector meson production at high Q^2, Q^2 giving here the scale. Measurements of the cross section $\sigma(\gamma^* p \to \rho p)$ show an indication for an increasingly stronger energy dependence when Q^2 increases [2,4]. With the parametrisation $\sigma \propto W^{\delta}$, we observe (see Fig. 1c) that at high Q^2 the value of δ for the ρ meson production seems to reach the one for J/ψ photoproduction.

4 Polarisation studies

Full helicity studies have been performed for the ρ and ϕ meson electroproduction [2,8]. In the helicity frame, three angles are used: the polar (θ) and azimuthal (φ) angles of the positive track in the vector meson centre of mass system (cms), and the Φ angle between the electron scattering plane and the vector meson production plane, in the hadronic cms. The decay angular distribution $W(\cos\theta, \varphi, \Phi)$ is a function of 15 matrix elements r_{ij}^{α} and $r_{ij}^{\alpha\beta}$, which are related to the helicity amplitudes $T_{\lambda_V \lambda_\gamma}$. The study of the angular distribution thus allows extracting information on the helicity states of the exchanged virtual photon and of the vector meson in the final state. Figure 2a presents the measurement of the 15 matrix elements as a function of Q^2. In case of s-channel helicity conservation (SCHC), the helicity of the vector meson is the same as that of the photon ($T_{01} = T_{10} = T_{1-1} = T_{-11} = 0$), and 10 of the matrix elements vanish (lines in Fig. 2a). It is the case for 9 of them but not for the r_{00}^5 parameter which is found to be significantly different from zero. The ratio of helicity flip to non helicity flip amplitudes is hence estimated to be 8.0 ± 3.0 %. The ratio of the longitudinal to the transverse cross section, $R = \sigma_L/\sigma_T$, can be extracted using the r_{00}^{04} matrix element. R is observed to increase with Q^2, and to reach the value R = 3 - 4 for $Q^2 \simeq 20$ GeV^2 (see Fig. 2b). The following hierarchy between the helicity amplitudes, observed in the data: $|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}|, |T_{1-1}|$, is in agreement with perturbative QCD calculations performed by Ivanov and Kirschner [9]. The Q^2 dependence of the ratio R is well described by the perturbative QCD models of Royen and Cudell [10], and of Martin, Ryskin and Teubner [11] and by the model of Schildknect, Schuler and Surrow [12] based on generalised vector dominance model (GVDM).

5 ψ' and Υ production

Signals for ψ' and Υ production have been observed recently at HERA [13,5,14]. The ratio of ψ'/ψ production cross sections is measured for four different Q^2 values ranging from 0 to 25 GeV^2 and an indication for a rise of the ratio as a function of Q^2 is observed. This can be understood as due to the "scanning" of the VM wave function as Q^2 varies. Indeed, in photoproduction, the Compton wave length of the photon is comparable to the radius of the ψ(2S) wave function. But the latter has a node which induces approximately cancelling contributions to the production amplitude, implying that the photoproduction of $\psi(2S)$ mesons is small. As Q^2 increases, the transverse size of the $q\bar{q}$ pair decreases, thus avoiding the cancellation effect.

The value of $\sigma(\gamma p \to \Upsilon p) * \mathrm{BR}(\Upsilon \to \mu^+\mu^-)$ for $Q^2 \simeq 0$ is measured to be, respectively, 16.0 ± 8.5 and 13.0 ± 6.6 pb by the H1 and ZEUS collaborations; due to limited statistics the data cannot distinguish between 1S, 2S and 3S states of the Υ meson. This measurement is described by two pQCD based models [15] when taking into account both the imaginary and real parts of the amplitude and introducing off-diagonal parton distributions, which leads to an enhencement of a factor $\simeq 5$ of the cross section normalisation.

6 Conclusions

Vector meson production have been studied at HERA in a wide kinematical range and for different vector mesons (from the ρ to the Υ mesons). The data show evidence for a hard behaviour of the energy dependence for the J/ψ photoproduction and a similar indication is

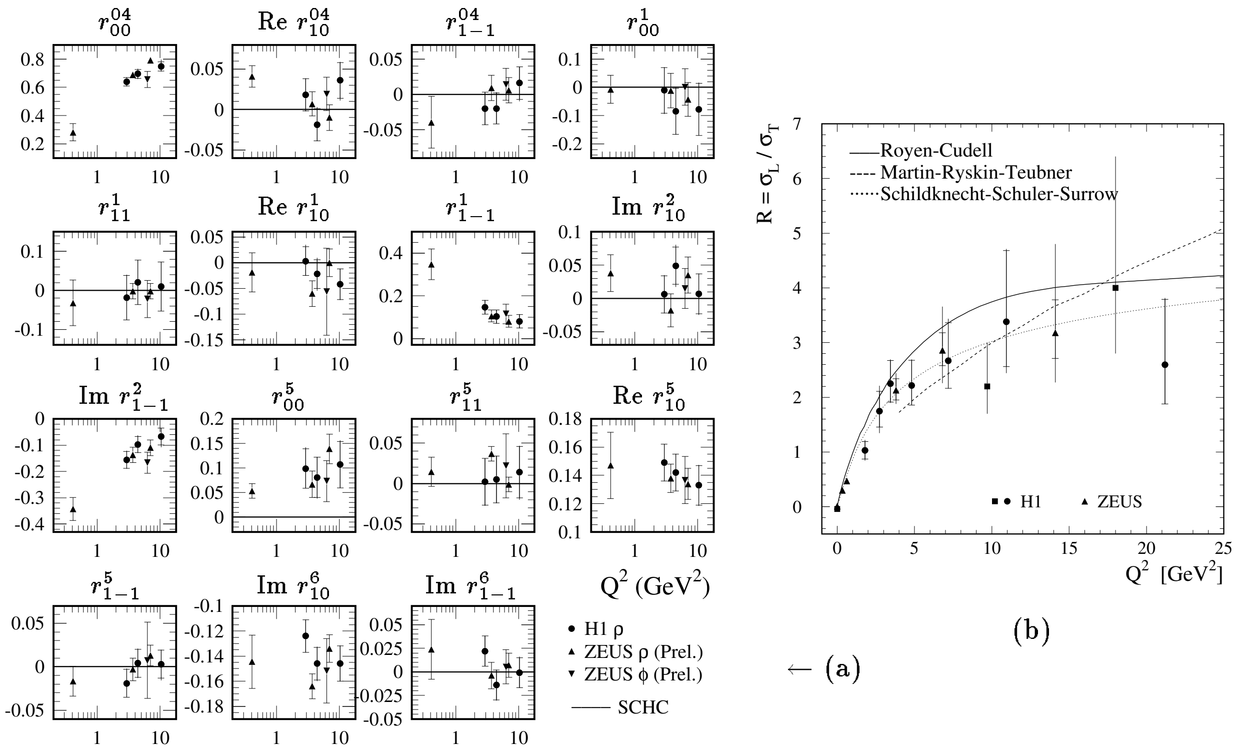

Figure 2: a) Measurements of the 15 elements of the ρ and ϕ spin density matrix as a function of Q^2. The lines represent the zero predictions in case of SCHC; b) Q^2 dependence of $R = \sigma_L/\sigma_T$, the lines being predictions of three models (see text).

found for ρ electroproduction ($Q^2 \gtrsim 10$ GeV^2). Full helicity studies have been performed for ρ and ϕ electroproduction, showing a small but significant violation of SCHC. The production of heavier vector mesons (ψ' and Υ) has also been observed recently at HERA.

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