Light Vector Meson Electroproduction at HERA

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Abstract

Selected recent results from the HERA experiment ZEUS on exclusive ρ^0, ω and ϕ electroproduction in ep collisions are reviewed .

1 Introduction

Vector meson production in lepton-proton collisions is a powerful probe to investigate the nature of diffraction. At HERA, because of large data sample and the wide kinematic ranges in the photon virtuality, Q^2, and in the hadronic center of mass energy, W, the details of the production mechanism can be investigated within a single experiment. It is also possible to select different vector mesons (VM), allowing the cross section for different quark types to be studied.

The simplest exclusive production process in diffractive ep scattering is the process $ep \to eVp$, where V is elastically produced ρ^0, ω and ϕ mesons. The simplicity of the final state in the exclusive production of VMs is very attractive for detailed investigation of the difftactive production mechanism. For high W exclusive photoproduction of light VMs displays features characteristic of soft diffractive processes, and is well described within the framework of the vector dominance model (VDM) [1] and Regge phenomenology [2]. In this approach exclusive VM production at high energies is assumed to proceed via the exchange of a Pomeron trajectory as shown in Fig. 1. The expectation of the VDM and Regge phenomenology is that the cross sections for exclusive VM production will be in proportions determined by the couplings of the photon to the vector mesons and by the elastic VM-proton cross sections. The couplings, in particular, are determined by the quark current decomposition of the photon and by the quark wave function of the VM. The $SU(4)$ prediction, which ignores the VM mass differences, is that the coupling strengths of the photon to the ρ^0, ω, ϕ and J/ψ mesons are in the ratio 9:1:2:8.

For high-energy exclusive photoproduction of heavy VMs and for electroproduction of all VMs at large virtualities, Q^2, of the exchanged virtual photon, $\gamma^\star$, an alternative production mechanism has been proposed [3],[4]: the virtual photon fluctuates into a $q\bar{q}$ pair before arriving at the target, and it is this $q\bar{q}$ state that scattered elastically off the proton. The VM is formed well after the interaction. These steps are depicted in Fig. 1. If the transverse size of the $q\bar{q}$ fluctuation is small enough, the interaction is expected to become flavour independent and the gluons of the proton are resolved [5]. Such a configuration occurs when the mass of the quarks is large or if the photon with large virtuality is longitudinally polarized. In these cases, perturbative QCD can be applied [3],[6] and the expectation for the ratios of VM production cross sections is given by the ratios of the couplings.

In this talk we consider exclusive electroproduction of ρ^0, ω and ϕ meson and discuss three topics : the first measurement of ω meson electroproduction, which has been completed the study of the W and Q^2 dependences of the cross section of all light VMs from the ZEUS data alone. The reported data permits to extend a discussion of the production cross section ratios on all light vector mesons .

2 Results

The detector of the ZEUS experiment is an all-purpose detector, excellently suited for detection and reconstruction of the vector meson decays and for distinguishing the pure elastic processes from those

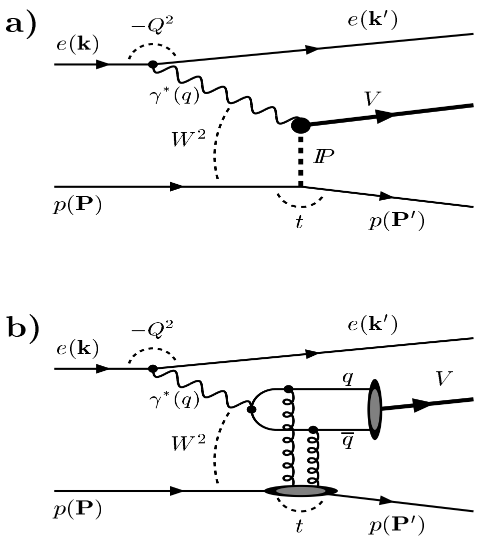

Figure 1: Diagrammatic depictions of the exclusive VM production (a) via pomeron exchange, and (b) via exchange of a gluon pair. The notation for the kinematic variables are: the photon-proton center-of-mass energy, W; the photon virtuality, Q^2; the square of the four-momentum transfer to the proton, t.

where the proton dissociates. In such p-dissociative reactions the few-body decay products of the vector meson are clearly separated from the low-mass multiparticle system resulting from the proton dissociation.

ω electroproduction The exclusive electroproduction of ω and ϕ mesons, $ep \to e\omega(\phi)p$, $\omega(\phi) \to \pi^+\pi^-\pi^0$, has been studied in the kinematic range $3 < Q^2 < 20\ GeV^2$, $40 < W < 120\ GeV$ and $|t| < 0.6\ GeV^{-2}$ with the ZEUS detector at HERA using an integrated luminosity of 37.7 pb^{-1}. This is the first measurement of ω meson production at large Q^2 at HERA.

The invariant mass spectrum of three pions for the $\pi^+\pi^-\pi^0$ is shown in Fig. 2. In addition to the ω signal a second peak at ϕ mass ($\phi \to \pi^+\pi^-\pi^0$) is visible. The mass spectrum was fitted with two Gaussians G_1, G_2 to describe ω and ϕ mass peaks and a polinomial P, representing the background:

$$f(M_{3\pi}) = G_1(M_{3\pi}) + G_2(M_{3\pi}) + P(M_{3\pi}).$$

The number of ω and ϕ mesons depends on the backgroud, which is mainly due to the background under the π^0 peak as well as to inelastic processes with an additionally produced π^0 meson.

The fitted values of the ω and ϕ meson masses and widths are $786 \pm 5\ MeV$ and $1021 \pm 10\ MeV$, respectively, compartible with their nominal values [7] and with MC. The values obtained for the widths of the two resonances are a measure of the resolution of the apparatus. The standard deviations of the Gaussian resolution function are 31 MeV for the ω and 30 MeV for the ϕ in accord with MC predictions. The number of ω and ϕ candidates observed after background subtraction was determined by integrating the corresponding Gaussian function within the kinematic limits. The results for the fit procedure with a second-oder Polinomial are $N_\omega = 113 \pm 15$ and $N_\phi = 35 \pm 12$.

The cross section for the ω and ϕ exclusive electroproduction in the kinematic range $3 < Q^2 <20\ GeV^2$, $40 < W < 120\ GeV$ and $|t| < 0.6\ GeV^{-2}$ found to be equal $\sigma_{ep\to e\omega p} = 0.108 \pm 0.014$(stat.) $\pm$ 0.026(syst.) nb and $\sigma_{ep\to e\phi p} = 0.220 \pm 0.064$(stat.) $\pm$ 0.077(syst.) nb. The corresponding $\gamma^\star p$ cross sections for the processes $\gamma^\star p \to \omega p$ and $\gamma^\star p \to \phi p$ at $Q^2 = 7\ GeV^2$ and $W = 70\ GeV$ are $8.5 \pm 1.1 \pm 2.0$ and $17.3 \pm 5.0 \pm 6.0$, respectively.

The measured cross section for exclusive ω production as a function of W is given in Table 1.

The W dependence of the $\gamma^\star p \to Vp$ cross sections The first measurement of the W dependence of the ω [8] cross section is compared to that found for the $\phi(\phi \to K^+K^-)$ [9] in Fig. 3. The observed dependence for ω electroproduction is consistent with that observed for the ϕ at a similar value of Q^2 and steeper than that measured in ω photoproduction [10] . In Fig. 4 shows the cross sections for elastic electroproduction of ρ^0 meson [11] plotted against W for a number of different values of Q^2. The measurements cover the range $5< Q^2 < 80\ GeV^2$ and $32 < W < 160\ GeV$. For comparison, previous

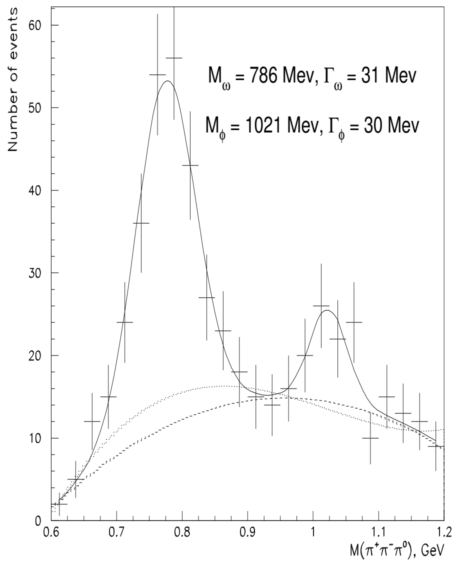

Figure 2: The invariant mass distribution of $\pi^+\pi^-\pi^0$ system. The solid line presents the result of the fit explained in the text. The dashed line shows the fitted background .

W $[GeV]$	Number of events	$\sigma_{\gamma^\star p\to\omega p}$ $[nb]$
50	34	$6.2 \pm 1.5 \pm 1.8$
70	30	$8.0 \pm 2.1 \pm 2.4$
100	59	$12.3 \pm 2.5 \pm 3.6$

Table 1: Exclusive ω production cross section for $|t| < 0.6\ GeV^{-2}$ and $Q^2 = 7\ GeV^{-2}$, measured at three W values.

ZEUS measurements at lower Q^2 [12], [13] are also shown. The energy dependence is well described by a power law $\sigma(W) \propto W^\delta$, and the steepness of the slope, δ, can be plotted against Q^2, as shown in Fig. 5, to look for evidence of perturbative effects as Q^2 is increased. There is clear evidence that the energe dependence is indeed steeper at high Q^2 than in photoproduction, where $\delta \simeq 0.2$, although the shape of the curve is not well constrained at the present level of accuracy. As can be seen from Fig. 5 , the W dependence of the cross section for the reaction $\gamma^\star p \to Vp$ is consistent with the 'soft' Pomeron approach at low values of Q^2. In the region of high Q^2, where QCD based models predict a steeper cross section dependence of W, a market increase of δ with Q^2 is observed.

The Q^2 dependence of the $\gamma^\star p \to Vp$ cross sections The measurements of ϕ meson cross section as a function of Q^2 are shown in Fig. 6. For $Q^2 > 5\ GeV^2$ the data are well described by the functional form $\sigma(Q^2) \propto (Q^2)^{-n}$. This type of parameterization does not describe data down to $Q^2 \simeq 0$. A similar Q^2 behavior has been observed for ρ^0 meson [11], where the measurment of Q^2 dependence of $\gamma^\star p \to \rho^0 p$ were extended up to $Q^2 = 80\ GeV^2$.

Cross section ratios

At sufficiently high scale values one expects that the VM production processes becomes independent of the participating quark flavour. It is also known that at low energies this expectation is not fulfilled.

The ω/ϕ, ω/ρ^0 and ϕ/ρ^0 cross section ratios, obtained using the $\phi \to \pi^0\pi^+\pi^-$ channel are listed in Table 2.

The ω/ρ^0 cross section ratios as a function of W is shown in Fig. 7. The ω/ρ^0 ratio does not depend on W at fixed Q^2 values.

The compilation of the ratio of ϕ and ω production cross sections to that of the ρ^0 as a function of

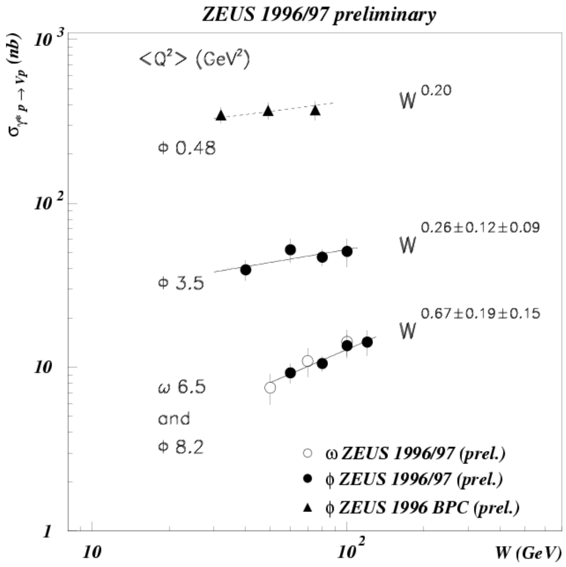

Figure 3: Cross sections for ω and ϕ production as functions of W. The solid lines and associated annotations show the results of fits to the ϕ cross sections. The dotted line shows a W dependence of the form $W^{0.20}$ for purposes of comparison.

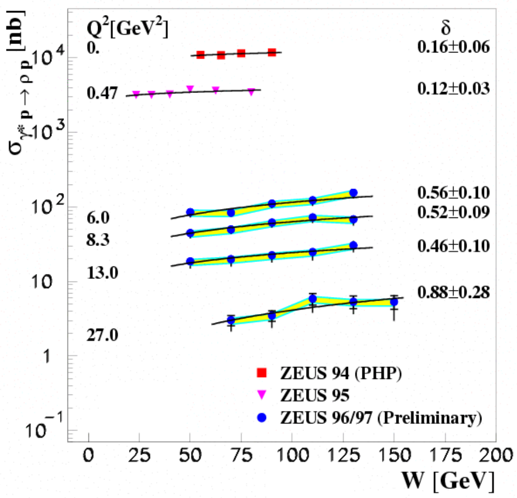

Figure 4: $\sigma_{\gamma^* p\to\rho p}$ as a function of W for different Q^2 values.The lines represent the result of a fit to the data with a functional form $\sigma(W) \propto W^\delta$.

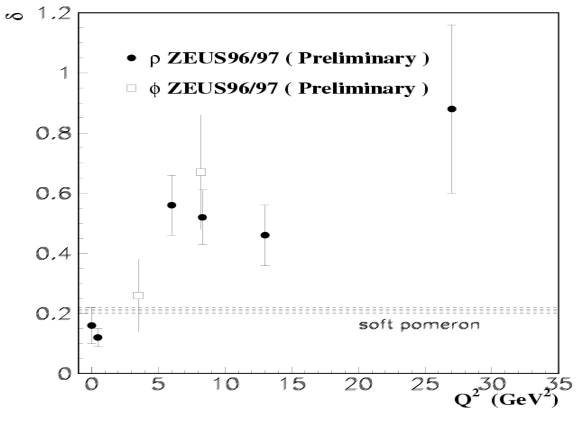

Figure 5: The values of δ as a function of Q^2 for exclusive production of ρ^0 .

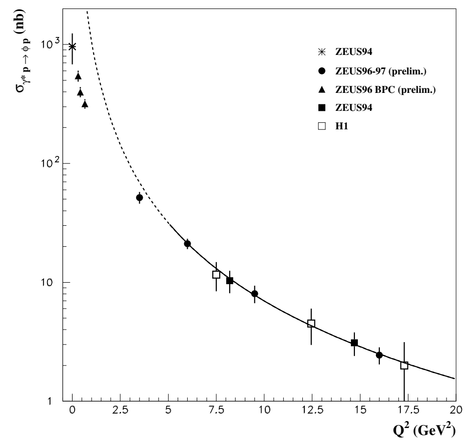

Figure 6: $\sigma_{\gamma^\star p \to \phi_{\to K^+K^-} p}$ as a function of Q^2. The solid line represents the result of a fit of the type $\sigma \propto 1/(Q^2)^n$ to the data with $Q^2 > 5\ GeV^2$. The dashed line is the extrapolation of the fit to $Q^2 = 0$.

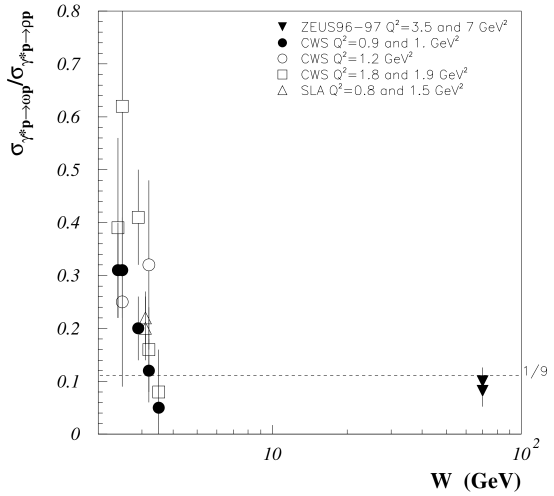

Figure 7: Cross section ratio ω/ρ^0 as a function of W .

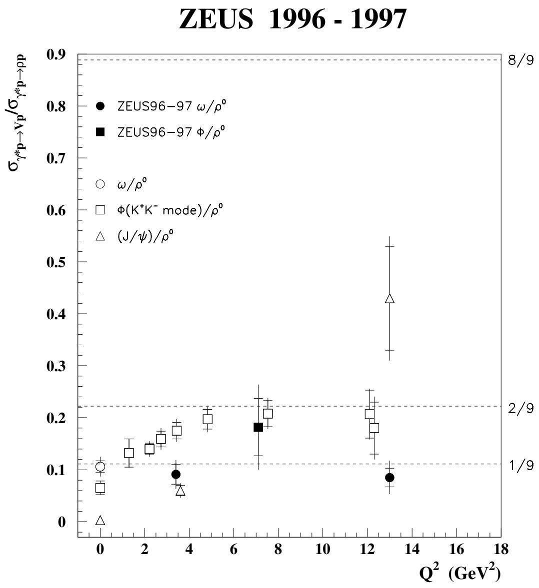

Figure 8: Cross section ratios $\sigma_{\gamma^\star p\to Vp}/\sigma_{\gamma^\star p\to\rho^0 p}$ as a function of Q^2. The $SU(4)$ predictions are indicated by dashed lines .

Cross-section ratio
$\sigma_{\gamma^\star p\to\omega p}/\sigma_{\gamma^\star p\to\rho^0 p} = 0.089 \pm 0.014 \pm 0.019$
$\sigma_{\gamma^\star p\to\phi p}/\sigma_{\gamma^\star p\to\rho^0 p} = 0.182 \pm 0.055 \pm 0.061$
$\sigma_{\gamma^\star p\to\omega p}/\sigma_{\gamma^\star p\to\phi p} = 0.49 \pm 0.15 \pm 0.12$

Table 2: Cross section ratios for ω, ϕ and ρ^0 mesons at $Q^2 = 7\ GeV^{-2}$ and $W = 70\ GeV$.

Q^2 is shown in Fig. 8. with the limits expected from $SU(4)$ indicated as dashed lines. For the light VMs good agreement is seen between the cross section ratios and the expectation. The present measurements confirm the significant rise of the ϕ/ρ^0 cross section ratio with Q^2: for $Q^2 \simeq 5\ GeV^2$ the cross section ratios approach the value 2/9, while it is suppressed at lower values of Q^2. No Q^2 dependence of the ω/ρ^0 cross-section ratio is observed. The ratio is consistent with the value expected from flavour independence.

Conclusions Due to its unique possibilities HERA is presently leading diffractive researches. Much has been learned from studying exclusive vector meson production, which fulfill the properties expected from perturbative QCD. The luminosity upgrade program scheduled for the year 2001 is expected to provide an increase in instantaneous luminosity of roughly a factor of five. This increase of a particular importance for study the transition from soft to hard regime.

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