# Study of Exclusive Vector Meson Production with H1

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**Abstract.** The H1 experiment at the ep-collider HERA at DESY in Hamburg, has investigated the diffractive production of vector mesons in photoproduction and at large photon virtualities, $Q^2$. The photoproduction of $\rho^0$ shows the characteristics of soft diffractive physics, as expected from Regge theory, whereas the heavier $J/\psi$ deviates from this picture. Its production is well described by QCD-models, relating the cross section to the gluon content of the proton. The $\rho^0$, $\phi$ and $J/\psi$ electroproduction cross sections are measured as a function of the hadronic centre of mass energy, $W_{\gamma p}$ and also differentially in $Q^2$ and the square of the four-momentum transfered, $t$. The helicity structure is studied through the decay angular distribution. The production of the higher mass excitations $\rho'$ and $\psi'$ has been observed. Electroproduction of $\rho^0$ with diffractive proton dissociation shows a similar behaviour to the elastic case, except for a harder $t$ spectrum.

## INTRODUCTION

At the HERA collider, photon-proton centre of mass energies, $W_{\gamma p}$ of up to 300 GeV are available - exceeding the energies of earlier fixed target experiments by an order of magnitude. At lower energy photoproduction of light vector mesons is well described by Regge theory together with the vector dominance model (VDM). Within this framework the photon is considered as a superposition of virtual vector meson states, one of which is placed on mass shell by the exchange of Regge trajectories with the proton (fig.1a). At HERA energies the pomeron trajectory dominates and the cross section is given by [1]:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t}|_{t=0} \propto W_{\gamma p}^{4(\alpha_P(0)-1)} = W_{\gamma p}^{4*0.0808} \tag{1}$$

with $\alpha_P(0) = 1.0808$ being the 'soft' pomeron intercept, determined from fits to total hadronic cross sections [2]. Perturbative QCD calculations have been performed (e.g. [3,4]), where the virtual vector meson state is replaced by a $q\bar{q}$ pair and two or more $t$-channel gluons are exchanged (fig.1b). In such models, the cross section is related to the gluon distribution in the proton, $xg(x,Q^2)$ by $\frac{d\sigma}{dt}|_{t=0} \propto \frac{[xg(x,Q^2)]^2}{Q^6}$, which can be expressed in terms of a 'hard' pomeron with intercept $\alpha_P(0) \approx 1.2$.

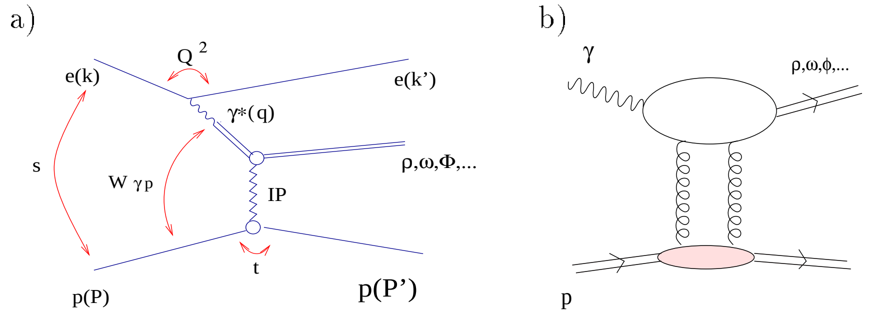


**FIGURE 1.** Vector meson production at HERA a) Regge-VDM model (including the definition of kinematic variables) b) pQCD models

A typical vector meson event selection requires two[1] tracks in the central tracking chamber with opposite charge. An upper limit is applied to the energy deposition in the main calorimeter not being assigned to the tracks. Proton dissociation events are rejected[2] by requiring no signal above noise in the forward detectors that are sensitive to the energy flow close to the outgoing proton direction [5]. This combination effectively removes events where the mass of the excited proton system is larger than 1.6 GeV. Non-resonant background is reduced by requiring $|t| < 0.5$ GeV$^2$. In the high $Q^2$ analyses a well formed electromagnetic shower in the backward calorimeter with an associated hit in the backward tracking chamber is required. The presented results were obtained with data taken in 1994[3].

## PHOTOPRODUCTION RESULTS

The $\rho^0$ [6] and $J/\psi$ [7,8] photoproduction cross sections have been measured in the range 30 GeV $< W_{\gamma p} <$ 150 GeV. Combined with low energy data, the cross section for $\rho^0$ production shows a slow rise with energy at high $W_{\gamma p}$ (fig. 2) as predicted for soft pomeron exchange. The $J/\psi$ shows a much steeper rise, incompatible with soft pomeron exchange, whereas a fit to the perturbative formulas in [3,4] describes the data well [8]. Due to the large charm quark mass, perturbative effects are already significant in photoproduction, as can

[1] four tracks for $\rho'$ and $\psi'$
[2] for the analyses with proton dissociation the cut is reversed
[3] except for $\rho^0$ (93+94) and $J/\psi$ (94+95) photoproduction

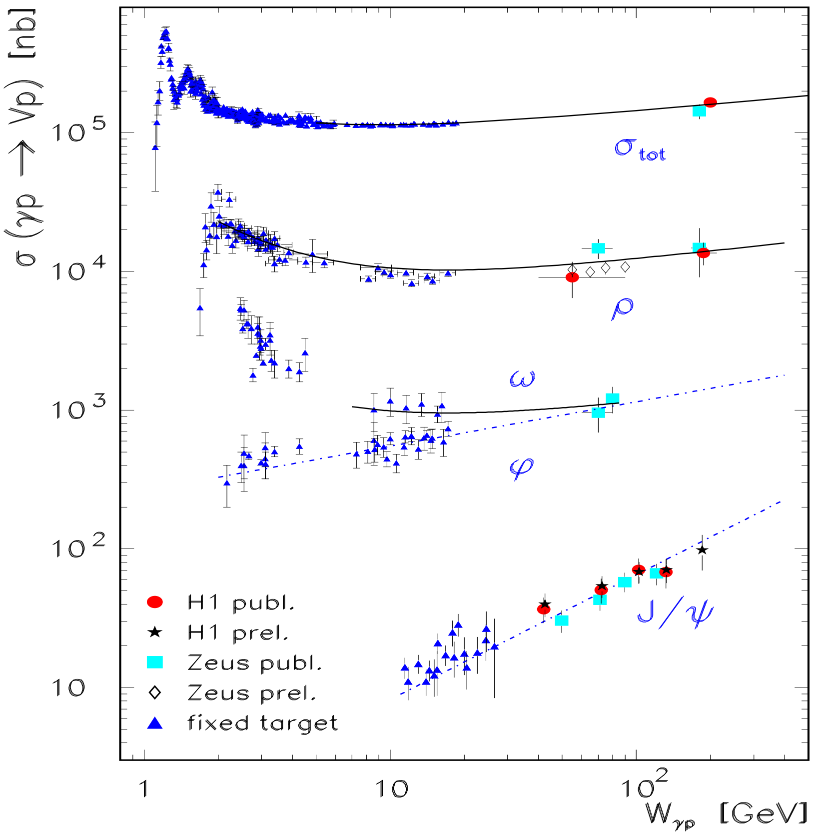


**FIGURE 2.** Compilation of photoproduction cross sections for different vector mesons compared to the total $\gamma p$ cross section. Shown are data from the HERA and fixed target experiments. The full lines are Regge type parameterisations [9]. The dashed lines are $W_{\gamma p}^{0.22}$ (integration over $|t|$ reduces 0.32 to 0.22 in (1)) and $W_{\gamma p}^{0.9}$. They are drawn to guide the eye [10].

be seen from the HERA data alone. Both mesons show an exponential fall-off of the cross section, $\frac{\mathrm{d}\sigma}{\mathrm{d}t} \propto e^{bt}$. For the $\rho$ meson the so called forward diffractive peak is more pronounced than at lower energies. This is referred to as 'shrinkage' and is predicted by Regge theory [1]. For the $J/\psi$ such a behaviour cannot be established from the data currently available. An analysis of the decay angular distribution, $\cos(\Theta^*)$[4] shows that the vector mesons are transversely polarised which is consistent with s channel helicity conservation (SCHC) (fig.3a). The measurement of $\psi'$ production [11] results in a cross section ratio of $\frac{\sigma_{\gamma p}(\psi(2S))}{\sigma_{\gamma p}(J/\psi)} = 0.16 \pm 0.06$. This agrees well with calculations taking the form of the vector meson wave function into account [12].

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[4] $\Theta^*$ is the polar angle of the positive decay particle in the vector meson rest frame with respect to its direction in the hadronic c.m.s.

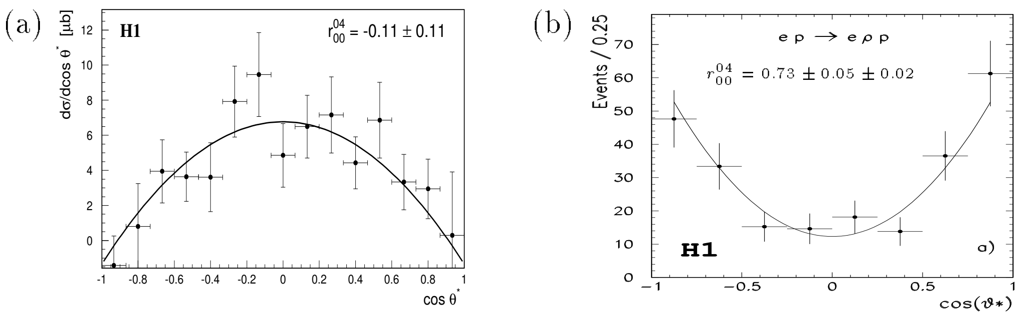


**FIGURE 3.** Decay angular distribution, for $\rho^0$ production (a) at $Q^2 \approx 0$ GeV$^2$ and for (b) $Q^2 > 8$ GeV$^2$. $r^{04}_{00}$ is the probability that the $\rho^0$ has been longitudinallly polarised.

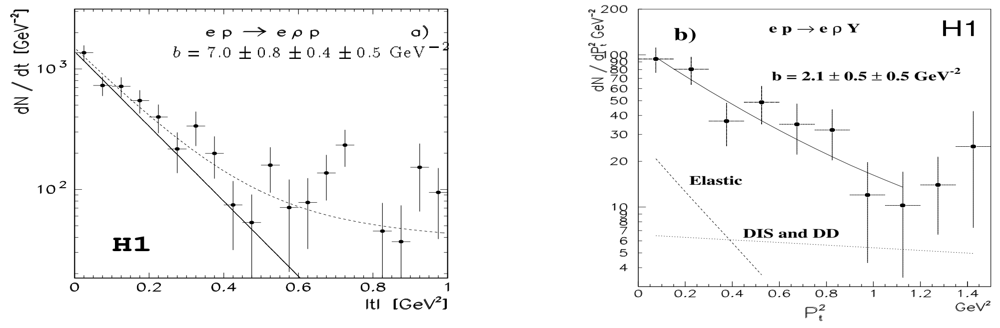


**FIGURE 4.** t dependence for $\rho^0$ electroproduction (a) elastic and (b) with proton dissociation ($|t|$ is reconstructed as $p_t^2$). The fits include contributions from various backgrounds with different b-slopes.

## RESULTS AT HIGH $Q^2$

H1 has measured the elastic production of $\rho^0, \phi$ and $J/\psi$ at $Q^2 > 6$ GeV$^2$ and electroproduction of $\rho^0$ with diffractive proton dissociation [13,14]. Compared to NMC results [15] the $\rho^0$ cross section shows a steeper rise with $W_{\gamma p}$ than at $Q^2 \approx 0$. New results from E665 [16] indicate however a slow rise with $W_{\gamma p}$, compatible with soft pomeron exchange, so further clarification is needed on this subject. Electroproduction of $\phi$ on the other hand shows a strong dependence on $W_{\gamma p}$. As in photoproduction, a diffractive peak is observed in the $t$ distributions (fig.4a). Assuming SCHC, the ratio of longitudinal to transverse cross sections has been extracted from the decay angular distributions of the $\rho^0$ (fig.3b) and $\phi$ mesons. They are produced predominantly longitudinally polarised. Fitting the form $(Q^2 + m_{vm}^2)^{-n}$ to the $Q^2$ distributions[5] yields values of $n \approx 2.0 - 2.5$ in agreement with theory [3,4] and values measured at fixed target experiments. The analysis of $\rho^0$ production with proton dissociation shows very much the same features as the elastic case, except for a smaller $t$-slope (fig. 4b). A comparison to ISR results shows consistency with

[5] the mass term is negligible for $\rho$ and $\phi$

factorization of the pomeron vertex, whereas for photoproduction of $J/\psi$ this seems not to be the case, although the errors are large [14]. The electroproduction of $\rho'$ [17] mesons has been analysed in the four pion decay mode. The cross section ratio $R_{\rho'/\rho} = 0.36 \pm 0.07 \pm 0.11$ is larger than in photoproduction, in agreement with theoretical expectations [18].

## CONCLUSION

The picture emerging from the presented analyses of exclusive vector meson production is that the transition from 'soft' to 'hard' physics seems to take place on two scales: the photon virtuality, $Q^2$ and the mass of the vector mesons' constituent quarks. While $\rho^0$ photoproduction is well described within Regge theory, the $J/\psi$ needs a perturbative approach, which now is established from HERA data alone. The analyses of data taken in 1995 and 1996 with much higher statistics will shed light on remaining questions, e.g. whether shrinkage is observed also in the perturbative regime and at which values of $Q^2$ the transition from soft to hard physics takes place for the $\rho^0$. A measurement of the $W_{\gamma p}$ dependence within one experiment is desirable and seems feasible with the new data. With the new backward calorimeter (SpaCal) installed in 1995, it will be possible to investigate the lower $Q^2$ region down to 1 GeV$^2$.

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