VECTOR MESONS AND pQCD AT HERA

S. MOHRDIECK (on behalf of the H1 and ZEUS collaborations)
Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

An overview of recent results from the H1 and ZEUS collaborations on vector meson production in electron-proton collisions at HERA is given. For diffractive vector meson production the energy dependence is discussed. The dependences on different scales, M_{VM}, Q^2 and $|t|$, are investigated. The data are compared to pQCD theoretical calculations. In addition new results on inelastic J/ψ electroproduction in a kinematical range $2 < Q^2 < 100\,\mathrm{GeV}^2$ and $50 < W_{\gamma p} < 225\,\mathrm{GeV}$ are shown. Differential cross sections are compared to theoretical predictions for color singlet and color octet contributions as well as to calculations for color singlet contributions alone.

1 Introduction

In ep scattering vector mesons are produced by two different production mechanisms. Diffractive vector meson production dominates the cross section in the elasicity region $z = \frac{P_p \cdot P_{VM}}{P_p \cdot P_{\gamma^*}} \simeq 1$, while inelastic processes contribute at lower z values. Here are P_p, P_{VM} and P_{γ^*} the four vectors of the proton, the vector meson and the exchanged photon. Other kinematic variables are the square of the four momentum exchange at the positron vertex Q^2, the energy of the $\gamma^* p$ system $W_{\gamma p}$ and, especially in diffraction, the four momentum exchange at the proton vertex $|t|$. Two different kinematical regions are distinguished: The range of quasi-real photon exchange ($Q^2 \simeq 0$) is called photoproduction, while electroproduction covers the region of higher photon virtualities ($Q^2 > 1\,\mathrm{GeV}^2$).

1.1 Diffractive vector meson production

In the case of diffraction a photon emitted from the incoming positron[a] diffracts off the proton by a colorless exchange producing an outgoing vector meson. Two subprocesses are distinguished: the elastic production in which the proton stays intact and proton dissociation in which the

[a] During the 1998 and part of 1999 data taking period HERA also ran with electrons

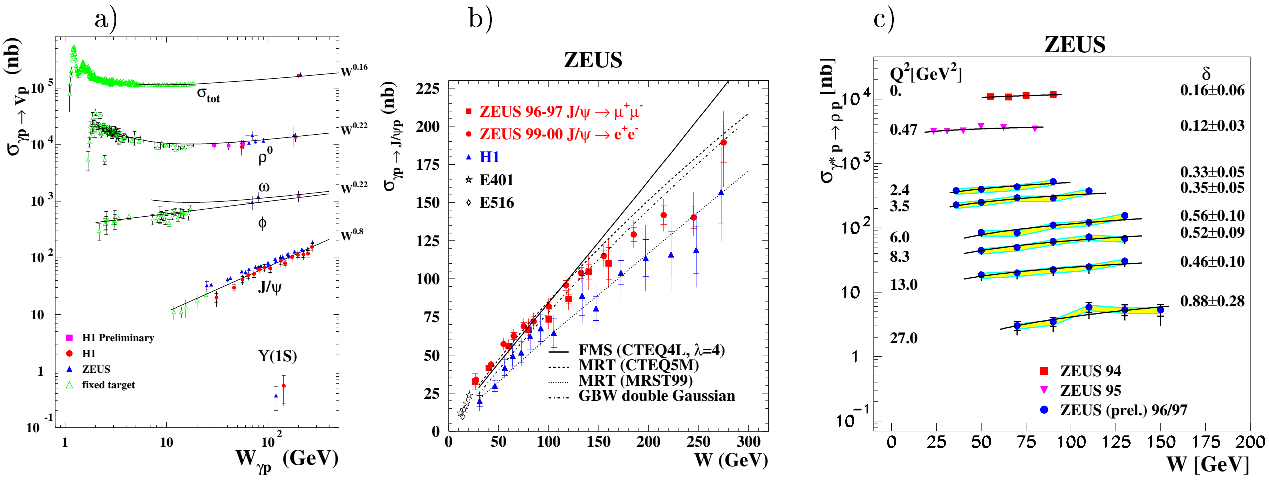

Figure 1: a) $W_{\gamma p}$ dependence for elastic photoproduction of different vector mesons. The lines show a behaviour of the cross section of the form $W_{\gamma p}^{\delta}$, where δ is indicated at the right edge. b) J/ψ meson photoproduction in comparison to theoretical calculations in pQCD. c) $W_{\gamma p}$ dependence of ρ meson electroproduction at different values of Q^2. The lines are fits of the form $W_{\gamma p}^{\delta}$.

proton breaks up. In the absence of a hard scale the colorless exchange can be modeled by a soft pomeron trajectory using the Regge approach. In this case the cross section is predicted to rise slowly with $W_{\gamma p}$. In the presence of a hard scale vector meson production can be calculated in the framework of perturbative QCD. In this case the colorless exchange is modeled by a pair of gluons or gluon ladder (with the quantum numbers of the vacuum). Therefore the cross section is proportional to the square of the proton gluon density and a steep rise with increasing $W_{\gamma p}$ is predicted.

1.2 Inelastic vector meson production

Inelastic vector meson production is dominated by the process of photon gluon fusion where a photon emitted by the incoming positron and a gluon as parton of the proton produce a $q\bar{q}$ pair. This $q\bar{q}$ pair can either be produced in a color singlet state by emission of a hard gluon or in a color octet state. The color singlet state can directly evolve into a real vector meson, while in the case of color octet states additional emission of soft gluons is necessary.
Here the data for J/ψ production are compared to two theoretical predictions[1] performed in non-relativistic QCD (NRQCD). The color singlet model (CS) includes only color singlet states, while the full calculation (CS+CO) takes in addition color octet contributions into account.

2 Results on diffractive production

HERA offers the unique possibility to study the dependences of diffractive processes on Q^2, the mass of the vector mesons M_{VM}^2 and $|t|$. The results presented cover a range up to $100\,\mathrm{GeV}^2$ in Q^2, $20 < W_{\gamma p} < 290\,\mathrm{GeV}$ and up to $20\,\mathrm{GeV}^2$ in $|t|$. The production of ρ, ω, ϕ, J/ψ and Υ mesons is studied.
The $W_{\gamma p}$ dependence for elastic vector meson photoproduction is shown in figure 1a). The lines indicate a behaviour of the cross section following a power law $W_{\gamma p}^{\delta}$. The light vector mesons ρ, ϕ and ω [2,3] show a slow $W_{\gamma p}$ dependence with a value for $\delta \simeq 0.22$, similar to the value that describes the total photoproduction cross section and well in agreement with predictions in the Regge approach. For the heavier vector meson J/ψ [4,5] a harder $W_{\gamma p}$ dependence is observed with a value $\delta \simeq 0.8$ as expected within pQCD predictions[6], that describe the J/ψ production data very well (figure 1b)). Improved statistics are required before firm conclusions can be drawn

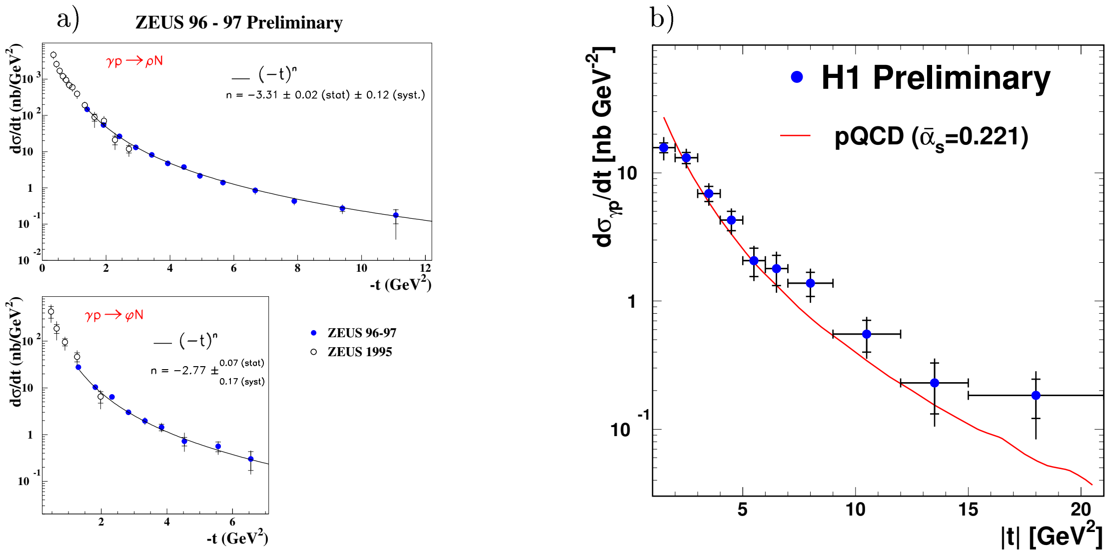

Figure 2: a) $|t|$ dependence in proton dissociative photoproduction for ρ and ϕ mesons. The lines indicate a fit $|t|^{-n}$. b) $|t|$ dependence for proton dissociative J/ψ production in comparison to a pQCD calculation.

for the Υ meson[4,5]. Figure 1c) shows the developement of the $W_{\gamma p}$ dependence with increasing mean values of Q^2 for ρ meson production[7]. Here the transition from a soft behaviour in photoproduction to a hard dependence in electroproduction is seen.

In addition to Q^2 and M^2_{VM} it is posdible that $|t|$ may provide a hard scale. At high $|t|$ proton dissociative production dominates the diffractive cross section. Within Regge approaches an exponential decrease of the differential cross section in $|t|$ is expected. However, calculations[8] using pQCD predict a decrease that follows a power law $|t|^{-n}$. In figure 2a) the differential photoproduction cross sections as a function of $|t|$ for the light vector mesons ρ and ϕ are presented[9]. A fit to $|t|^{-n}$ is shown which agrees with the expectation of pQCD. Figure 2b) presents the proton dissociative cross section of J/ψ photoproduction[10] compared to a pQCD calculation[11]. Good agreement is found. Both observations indicate that $|t|$ provides a hard scale in diffractive vector meson production such that pQCD can be applied at large $|t|$.

3 Results on inelastic production

New results[12] on inelastic J/ψ electroproduction in the kinematic range of $2 < Q^2 < 100\,\mathrm{GeV}^2$, $50 < W_{\gamma p} < 225\,\mathrm{GeV}$, $0.3 < z < 0.9$ and $p_t^{*2} > 1\,\mathrm{GeV}^2$ are presented in figure 3. Differential *ep* cross sections as a function of Q^2 (a) and the squared transverse momentum of the J/ψ meson in the $\gamma^* p$ system p_t^{*2} (b) are shown as well as the normalized differential cross section in z (c). The data are compared to two theoretical predictions[1] in leading order performed in the framework of NRQCD. With the light grey band the calculation for color singlet contributions (CS) alone is shown, while the dark band represents the full prediction including color singlet and color octet contributions (CS+CO). The CS prediction falls below the data by almost a factor of three and has a too steep p_t^{*2} dependence. Note, however, that higher order processes are expected to contribute significantly at high values of p_t^{*2} as observed in next-to-leading order calculations for CS contributions in the photoproduction limit[13]. On the other hand the behaviour of the cross section in z is well described. The calculation including both CS and CO contributions shows the right depencence and magnitude of the cross section at high Q^2 and p_t^{*2}, while it fails to describe the data at high values of z. This discrepancy may be due to phase space limitations at high z for the emission of soft gluons in the transition from the color octet $c\bar{c}$ pair to the J/ψ meson, which are not taken into account in the calculation.

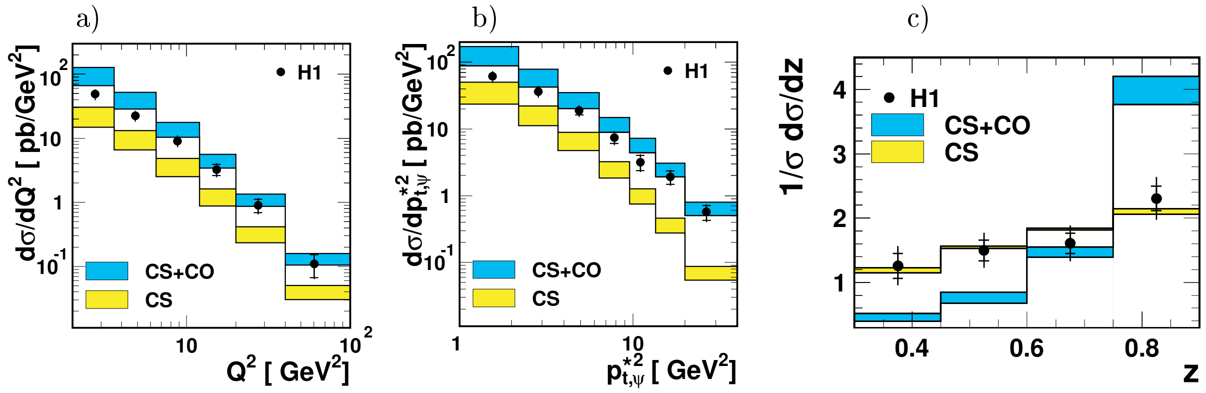

Figure 3: a) Differential ep cross section in Q^2 (a), p_t^{*2} (b) and z (c) for inelastic J/ψ electroproduction. In c) the cross section is normalized. The data are compared to theoretical prediction in NRQCD for the color singlet contributions alone (CS, light grey) and for the sum of color singlet plus color octet contributions (CS+CO, dark).

Conclusions

HERA offers the unique possibility to study the transision region from soft to hard diffraction in vector meson production. The $W_{\gamma p}$ dependence of the cross section for different vector mesons and at different values of Q^2 as well as the $|t|$ dependence of the cross section were presented. A clear indication that Q^2, M_{VM}^2 and $|t|$ provide a hard scale is found. In the presence of a hard scale perturbative QCD calculations describe the data well.
In addition new results on inelastic J/ψ electroproduction were shown and compared to leading order theoretical predictions in NRQCD for color singlet contributions alone and the full calculation including color singlet and color octet contributions. The CS calculation falls below the data by a factor of 3, while the CO+CS prediction is in good agreement with the data at high Q^2 and p_t^{*2}.

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