Vector Meson Production at HERA

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Abstract

An overview of the recent results from the H1 and ZEUS collaborations on diffractive vector meson production in electron-proton collisions at HERA is presented. Results for elastic and proton-dissociative production in W, Q^2 and $|t|$ are shown. The data are compared to pQCD theoretical calculations.

1 Introduction

At HERA, the incoming electron can scatter emitting a real or virtual photon which then diffracts off the proton producing an outgoing vector meson. These processes can be divided into elastic scattering processes in which the proton stays intact and proton dissociative processes in which the proton breaks up. HERA offers the unique possibility to study the dependences of diffractive processes in the photon virtuality Q^2, the four-momentum-transfer squared t at the proton vertex and the mass M_{VM} of the produced vector meson. The results presented cover a range up to $100\,\mathrm{GeV}^2$ in Q^2, photon-proton centre-of-mass energies $20 < W < 290\,\mathrm{GeV}$ and up to $20\,\mathrm{GeV}^2$ in $|t|$. The production of ρ, ω, ϕ, J/ψ, ψ' and Υ mesons can be studied.

In the absence of any hard scale diffractive vector meson production can be described using the Regge approach, with the photon fluctuating into a vector meson before it interacts with the proton via the exchange of one universal pomeron trajectory $\alpha(t) = \alpha_0 + \alpha' t$. The t dependence of the cross section is usually parameterised by an exponential function: $\mathrm{d}\sigma/\mathrm{d}t \propto e^{-b|t|}(W/W_0)^{4(\alpha_0-1)}$. The slope parameter $b = b_0 + 4\alpha' \ln(W/W_0)$ is expected to rise with W ('shrinkage'). The total cross section is expected to rise slowly with W ($W^{0.22...0.32}$).

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In the presence of a hard scale predictions within the framework of perturbative QCD become possible. In these models the interaction between the photon and the proton factorises into three parts: the fluctuation of the photon into a $q\bar{q}$ pair, the interaction via exchange of a 'reggeized' gluon ladder (with the quantum numbers of the vacuum) and the formation of the vector meson. The total cross section can be used to extract the gluon density in the proton and is expected to rise steeply with W. Only a much smaller shrinkage has been predicted.

2 Elastic Photoproduction

In photoproduction the incoming photon is quasi-real: $Q^2 < 1\,\mathrm{GeV}^2$. Possible hard scales are only the mass of the produced vector meson and t. While for light vector mesons the W dependence is compatible with the expectations of soft pomeron exchange, J/ψ production has a steeper behaviour. In figure 1 (a) the cross section is shown as a function of W with a fit of the form $\sigma \propto W^\delta$ and in figure 1 (b) together with predictions based on perturbative QCD. The extracted powers $\delta = 0.65 \pm 0.03(stat) \pm 0.09(syst)$ (ZEUS) and $\delta = 0.83 \pm 0.07$ (H1) ar both considerably larger than the expectation of 'soft' pomeron exchange. The predictions in the pQCD framework [3,4] describe the data, but suffer from large normalization uncertainties. Both the shape and normalization depend strongly on the parametrization of the gluon density. The two models (MRT and FKS) differ mainly in their descriptions of the bound state.

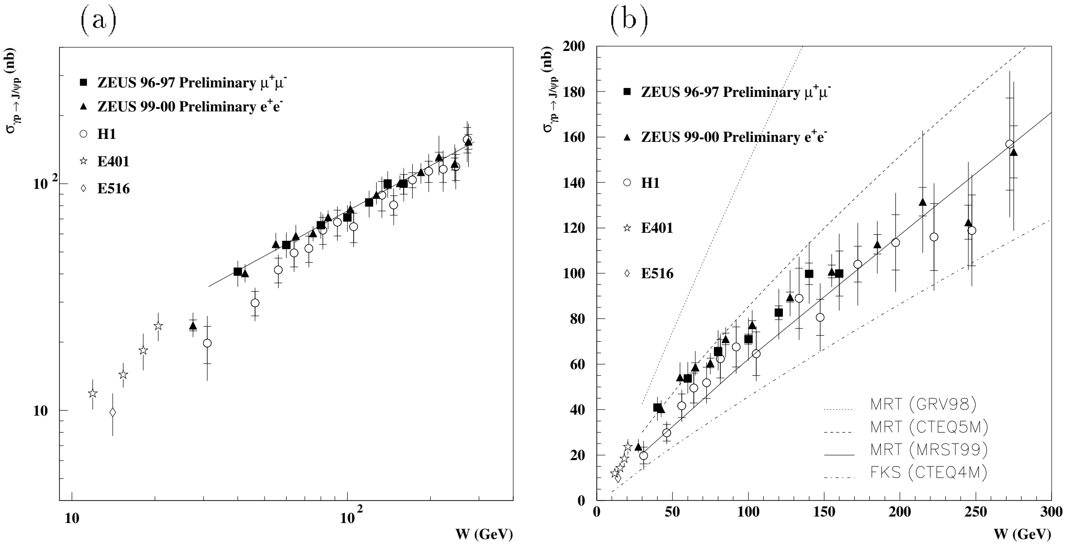

Fig. 1. Photoproduction cross section for elastic J/ψ production as a function of the photon-proton centre-of-mass energy W [1,2] (a) with a fit with a power law $\sigma_{\gamma p} \propto W^\delta$ and (b) in comparison with predictions based on pQCD calculations [3,4].

In the Regge approach the W dependence of the differential cross section $\mathrm{d}\sigma/\mathrm{d}t \propto W^{4(\alpha(t)-1)}$ offers the possibility to measure the pomeron trajectory directly. The trajectory extracted from measurements of the elastic photoproduction of J/ψ mesons [1,2] is shown in figure 2. Both measurements lie between the soft [5] and the hard [6] pomeron proposed by Donnachie and Landshoff, whereas the intercept α_0 is in good agreement with the hard pomeron prediction based on NLO BFKL [7].

3 Elastic Electroproduction

In electroproduction the non-zero photon virtuality Q^2 provides a hard scale. Therefore an increasing deviation from soft pomeron behaviour is expected with increasing Q^2. For light vector mesons, the W dependence of elastic ρ production [8] is shown for fixed Q^2 together with fits of the form $\sigma \propto W^\delta$ (figure 3 (a)). An increase of δ with Q^2 is observed. In the case of the J/ψ meson, where the c quark mass is expected to provide a hard scale, a large

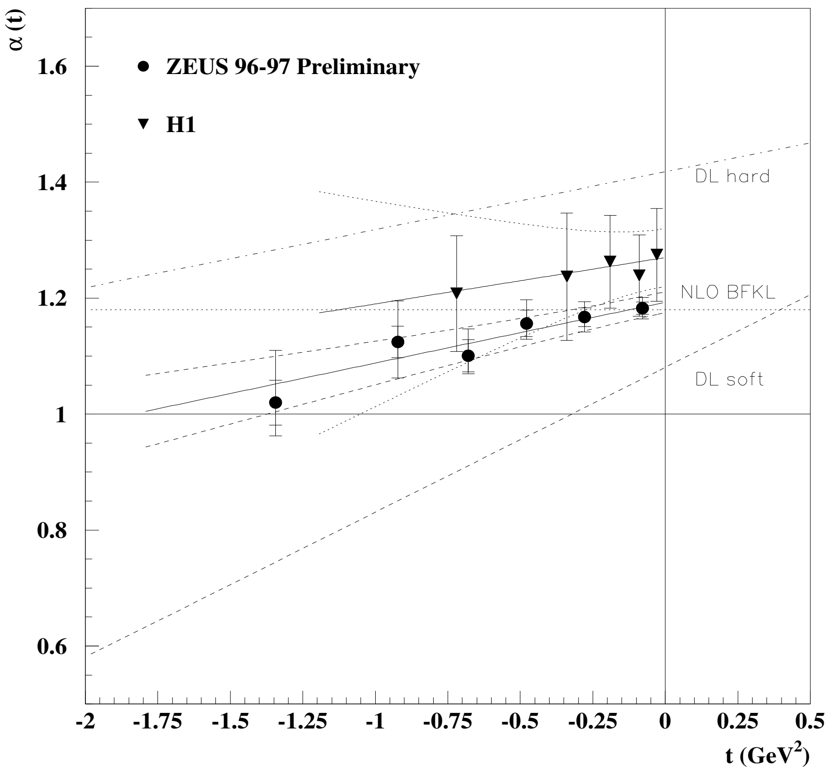

Fig. 2. Pomeron trajectory as a function of t measured in elastic J/ψ photoproduction. Also shown are the soft (dashed line) and hard (dot-dashed line) DL pomeron trajectories and a prediction for the pomeron intercept based on NLO BFKL.

value of δ is already present in photoproduction. No significant dependence on Q^2 is found [9,10] (fig. 3 (b)). Models based on pQCD [3,11] are able to describe J/ψ production.

At 'sufficiently large' values of Q^2 it is expected that vector meson production becomes independent of the participating quark flavour. Under the assumptions of a point-like electromagnetic coupling of the photon to the quark charges, and of the universality of the coupling between the $q\bar{q}$ pair and the meson (i.e. no dependency on the meson wave function), the SU(4) ratios $9 : 1 : 2 : 8$ are expected for the ρ, ω, ϕ and J/ψ meson production cross sections. Figure 4 shows the the ratios of ω, ϕ and J/ψ to ρ production as a function of Q^2. At low Q^2 the ratios for ϕ and J/ψ mesons lie clearly below the SU(4) expectation. At high Q^2 all ratios are in agreement with this expectation. For the J/ψ meson the ratio approaches the value expected from SU(4) only at much larger Q^2 values than for the lighter mesons.

4 Vector Meson Production at high $|t|$

In order to study whether $|t|$ also provides a hard scale, the photoproduction of light vector mesons at high $|t|$ has been measured. In figure 5 the differential cross section $\mathrm{d}\sigma/\mathrm{d}t$ for the photoproduction of ρ and ϕ mesons [12] is shown. While at low $|t|$ the data are in agreement with an exponential drop, the high $|t|$ data can be described by a power-like dependence in $|t|$, as expected for a hard production mechanism [13].

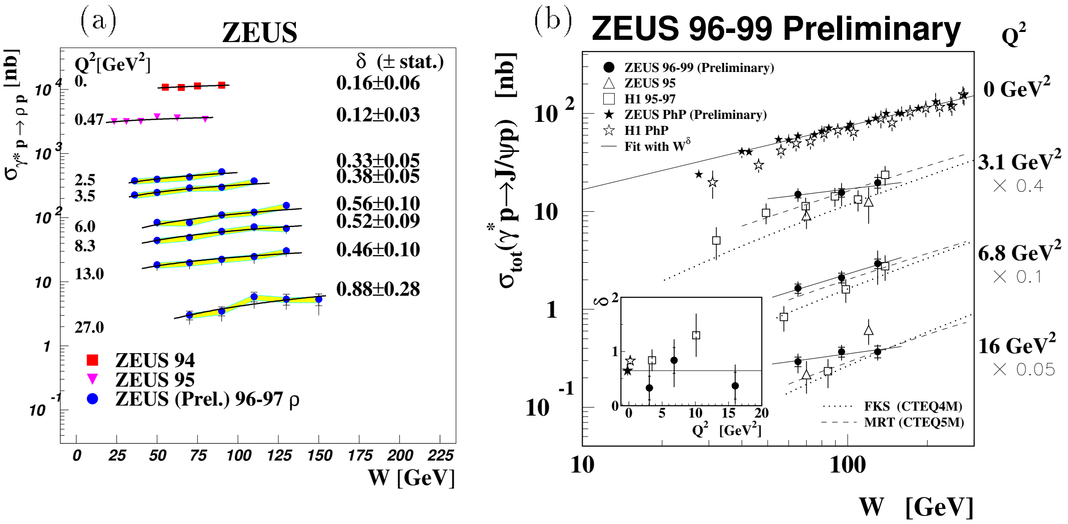

Fig. 3. W dependence of the elastic VM production cross section for fixed Q^2 for (a) ρ mesons and (b) J/ψ mesons. The data are shown together with fits of the form W^{δ} (full lines) and predictions based on pQCD (dashed and dotted lines). The insert in (b) shows the Q^2 dependence of δ.

The differential cross section $d\sigma/dt$ for J/ψ photoproduction [12,14] is shown in figure 6. The measurements are in agreement with calculations based on pQCD [15]. The ZEUS data are described by a power-like dependence in $|t|$ with a power $n = -1.7 \pm 0.2(stat) \pm 0.2(syst)$.

The decay angular distribution $W(\cos\theta, \phi, \Phi)$ for electroproduction of vector mesons depends on 15 density matrix elements r_{ij}^{α} and $r_{ij}^{\alpha\beta}$ which are related to the helicity amplitudes $T_{\lambda_V \lambda_\gamma}$. Under the assumption of s-channel helicity

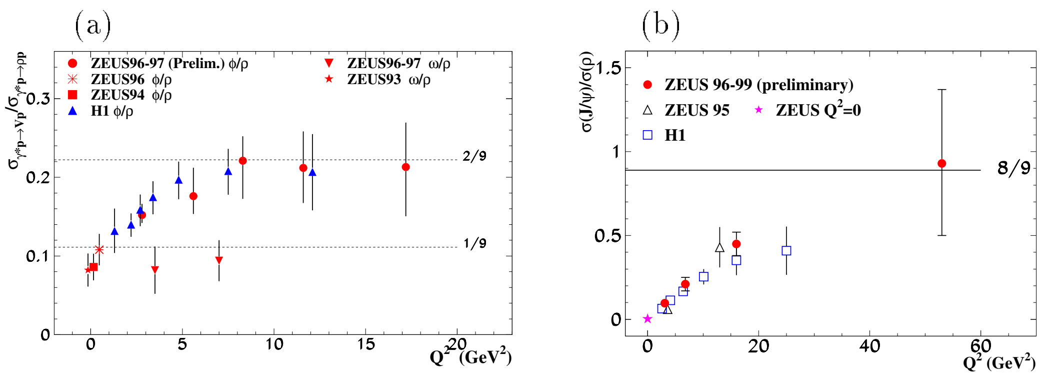

Fig. 4. Cross section ratios (a) σ_ϕ/σ_ρ, $\sigma_\omega/\sigma_\rho$ and (b) $\sigma_{J/\psi}/\sigma_\rho$ as a function of Q^2. The lines show the values expected from SU(4).

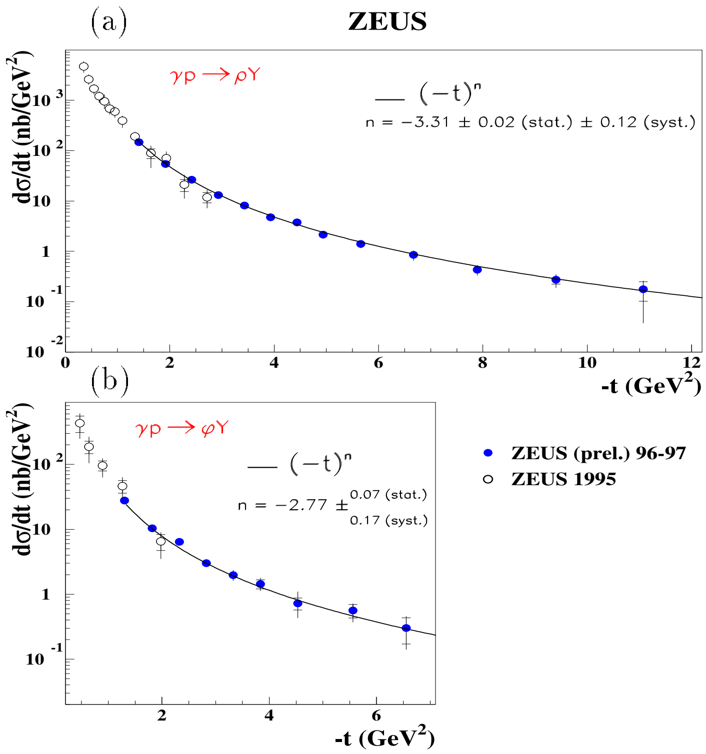

Fig. 5. Differential cross section $d\sigma/dt$ as a function of $-t$ for (a) ρ and (b) ϕ photoproduction with proton dissociation. The lines show fits of the form $(-t)^n$.

conservation (SCHC) and natural parity exchange (NPE) 10 of the 15 matrix elements are zero. Figure 7 shows the measurement [16] of the density matrix element r^{04}_{00} and the linear combinations $r^5_{00} + 2r^5_{11}$ and $r^1_{00} + 2r^1_{11}$ as a function of $t' = |t| - t_{min}$ for ρ electroproduction with proton dissociation, where t_{min} is the minimum value of $|t|$ kinematically required to put the ρ meson and the proton dissociative system on mass shell. While r^{04}_{00} shows no significant dependence on t', an increasing violation of the expectation of s-channel helicity conservation is observed for the combination $r^5_{00} + 2r^5_{11}$. A hint of a negative value of $r^1_{00} + 2r^1_{11}$, which is expected to be zero under SCHC and NPE, is found at high t'. All measurements can be described by fits with t' dependences as expected from pQCD calculations [17].

5 Conclusions

Vector meson production has been studied at HERA in a wide kinematic range in Q^2, W and $|t|$. The elastic photo- and electroproduction of J/ψ mesons as well as the electroproduction of ρ mesons show a strong W dependence as expected from pQCD models. The pomeron trajectory extracted from J/ψ photoproduction is not compatible with the soft pomeron alone, but the intercept is in agreement with a NLO BFKL calculation. Differential cross sections $\mathrm{d}\sigma/dt$ for the photoproduction of ρ, ϕ and J/ψ mesons are consistent with a power-like dependence on $-t$, as expected for a hard production mechanism. Helicity studies of proton-dissociative ρ electroproduction show an increasing violation of SCHC with $t' = |t| - t_{min}$.

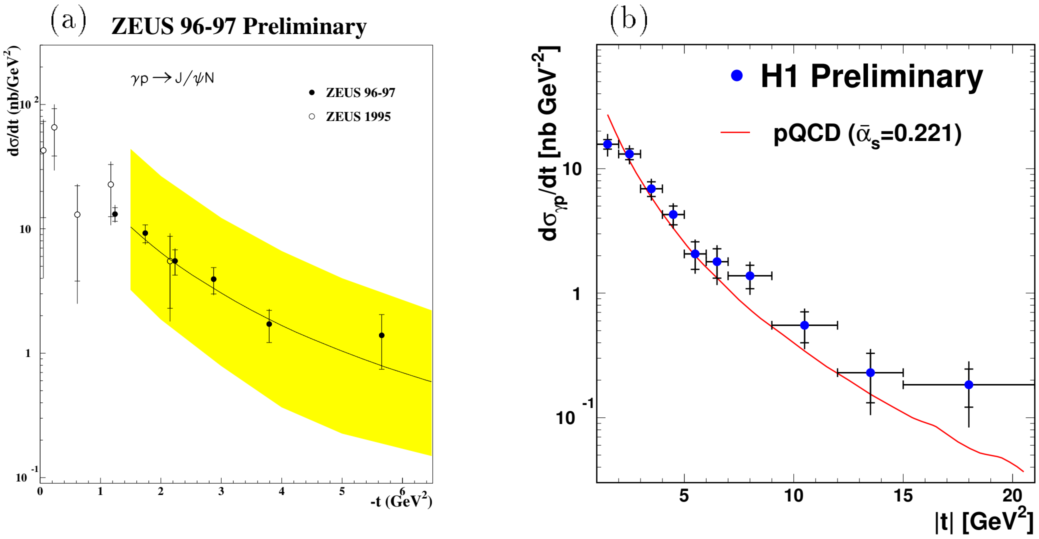

Fig. 6. Differential cross section $\mathrm{d}\sigma/dt$ as a function of $-t$ for J/ψ photoproduction with proton dissociation. The lines show calculations based on pQCD.

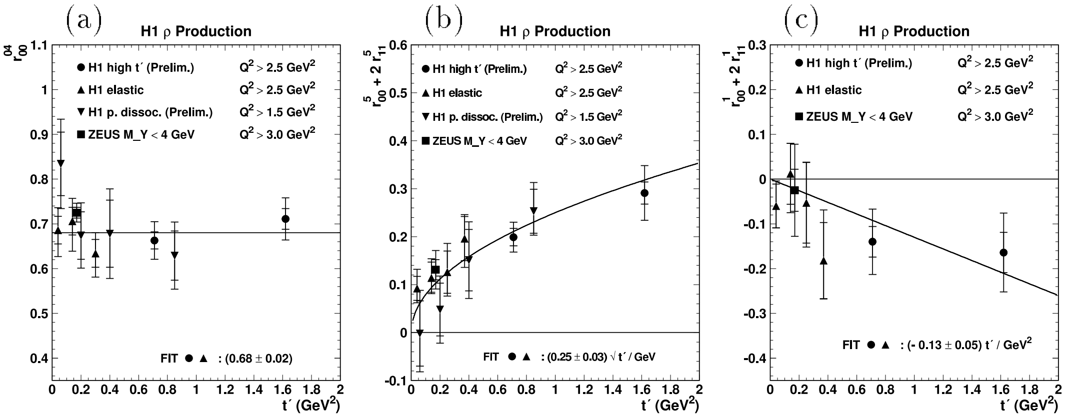

Fig. 7. Density matrix element (a) r^{04}_{00} and the combinations (b) $r^5_{00} + 2r^5_{11}$ and (c) $r^1_{00} + 2r^1_{11}$ for ρ meson electroproductio as a function of $t' = |t| - t_{min}$. The lines show fits with t' dependences as expected from pQCD calculations.

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References

[1] H1 Collaboration, C. Adloff et al., Phys. Lett. B **483** (2000) 23

[2] ZEUS Collaboration, J. Breitweg et al., *Exclusive photoproduction of J/ψ mesons*, contributed paper 878 to ICHEP00, Osaka

[3] L. Frankfurt, W. Koepf and M. Strikman, Phys. Rev. D **57** (1998) 512

[4] A. D. Martin, M. G. Ryskin and T. Teubner, Phys. Lett. B **454** (1999) 339

[5] A. Donnachie and P. V. Landshoff, Phys. Lett. B **348** (1995) 213

[6] A. Donnachie and P. V. Landshoff, Phys. Lett. B **437** (1998) 408; A. Donnachie and P. V. Landshoff, Phys. Lett. B **470** (1999) 243

[7] S. J. Brodsky et al., JETP Lett. **70** (1999) 155

[8] ZEUS Collaboration, J. Breitweg et al., *Exclusive electroproduction of ρ^0 mesons at HERA*, contributed paper 594 to EPS2001, Budapest

[9] ZEUS Collaboration, J. Breitweg et al., Eur. Phys. J. C **6** (1999) 603; ZEUS Collaboration, J. Breitweg et al., *Exclusive electroproduction of charmonium at HERA*, contributed paper 879 to ICHEP00, Osaka

[10] H1 Collaboration, C. Adloff et al., Eur. Phys. J. C **10** (1999) 373

[11] A. D. Martin, M. G. Ryskin and T. Teubner, Phys. Rev. D **62** (2000) 014022

[12] ZEUS Collaboration, J. Breitweg et al., *Measurement of proton-dissociative diffractive photoproduction of vector mesons at large momentum transfer at HERA*, contributed paper 556 to EPS2001, Budapest

[13] L. Frankfurt and M. Strikman, Phys. Rev. Lett. **63** (1989) 1914; A. H. Mueller and W. K. Tang, Phys. Lett. B **284** (1992) 123

[14] H1 Collaboration, C. Adloff et al., *Proton Dissociative J/ψ Production at High $|t|$ at HERA*, contributed paper 806 to EPS2001, Budapest

[15] J. Bartels, J. R. Forshaw, H. Lotter and M. Wusthoff, Phys. Lett. B **375** (1996) 301

[16] H1 Collaboration, C. Adloff et al., *Measurement of density matrix elements for ρ meson production as a function of t at HERA*, contributed paper 796 to EPS2001, Budapest

[17] E. V. Kuraev, N. N. Nikolaev and B. G. Zakharov, JETP Lett. **68** (1998) 696