Exclusive Electroproduction of Charmonium at HERA

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on behalf of the H1 and ZEUS collaborations

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Abstract. Exclusive electroproduction of charmonium (J/ψ) in ep collisions at HERA has been studied by both H1 and ZEUS using integrated luminosities of $27\,\mathrm{pb}^{-1}$ and $75\,\mathrm{pb}^{-1}$, respectively. The J/ψ state is identified via its leptonic decay channels. Cross sections have been measured as functions of Q^2 and W. Angular distributions of the decay leptons have been measured and the ratio $R = \sigma_L/\sigma_T$ is extracted as a function of Q^2.

INTRODUCTION

Vector Dominance Model (VDM) in conjunction with Regge phenomenology has described vector meson (VM) production in the measurements of elastic photoproduction of the light VMs (ρ, ω and ϕ) performed both in fixed target experiments [1–4] and at HERA [5–10]. At sufficiently high energies ($W > 10\,\mathrm{GeV}$, where W is the center-of-mass energy of the γp system.), the reaction displays the characteristics of a diffractive soft process, most notably a slow rise of the cross section ($\propto W^{\delta}$, $\delta \simeq 0.22$). However, a different cross-section behavior has been observed in J/ψ photoproduction [11]; the cross section rises more rapidly with W ($\delta \simeq 0.6 - 0.9$). This is inconsistent with such a soft production mechanism. A similar steep W-dependence is observed in the exclusive electroproduction of the light VMs. At Q^2 values close to the J/ψ mass squared ($Q^2 \approx M^2_{J/\psi}$), the observed W-dependence [12,13] yields values of δ ($\simeq 0.4 - 0.7$) similar to those obtained in J/ψ photopro-

duction. Here, Q^2 indicates the negative four-momentum transfer squared at the lepton vertex or virtuality of the exchanged photon (γ^*).

An alternative approach to VM production based on perturbative QCD (pQCD) has been proposed when a hard scale is available. The reaction is understood as a scattering between the proton and a color dipole ($q\bar{q}$) into which the virtual photon fluctuates, mediated by two gluons in a color singlet state. Long after this interaction, the dipole forms a J/ψ state. The cross section is, in the leading-log approximation, proportional to the square of the gluon density in the proton, $[xg(x,\mu^2)]^2$. It is interesting to study the interplay of the two hard scales, Q^2 and $M^2_{J/\psi}$, because the hard scale μ can be given by a combination of them. The observed steep rise in the cross section is explained by the rapid increase of the gluon density towards low x, since $W^2 \propto 1/x$ at fixed Q^2.

The study of J/ψ electroproduction has been performed with the recent high-luminosity data sets from HERA. This talk is based on the H1 published results [15] using $27\,\mathrm{pb}^{-1}$ taken in 1995-97 and the ZEUS preliminary results [16] using $75\,\mathrm{pb}^{-1}$ taken in 1996-99. In both analyses, a scattered e is tagged with the calorimeter, and the J/ψ state is identified via its leptonic decay channels, requiring two oppositely-charged tracks in the central tracker not associated with the scattered e. Measured ep cross sections are translated into γ^*p ones as functions of Q^2 and W.

W-DEPENDENCE

Figure 1 shows the measured cross sections as a function of W at three Q^2 values, 3.1, 6.8 and $16\,\mathrm{GeV}^2$. For the H1 data, the cross sections at the Q^2 values, 3.5, 10.1 and $33.6\,\mathrm{GeV}^2$ have been rescaled according to the Q^2-dependence from the H1 measurement described in the next section. The cross sections at each Q^2 value are fitted with the function W^δ. The solid lines in Figure 1 are the results of the fit to the ZEUS data. The resulting δ values for the H1 and ZEUS data are shown in the inset of Figure 1. The obtained W-slopes in electroproduction are consistent with those of photoproduction by H1 [17] and ZEUS [18]. The cross sections are also compared with the pQCD-based calculations from Frankfurt et al. (FKS) [19] using CTEQ4M and from Martin et al. (MRT) [20] using CTEQ5M. The theories and the data are consistent within the uncertainty of the measurements although the rise with W predicted by these calculations tends to be steeper.

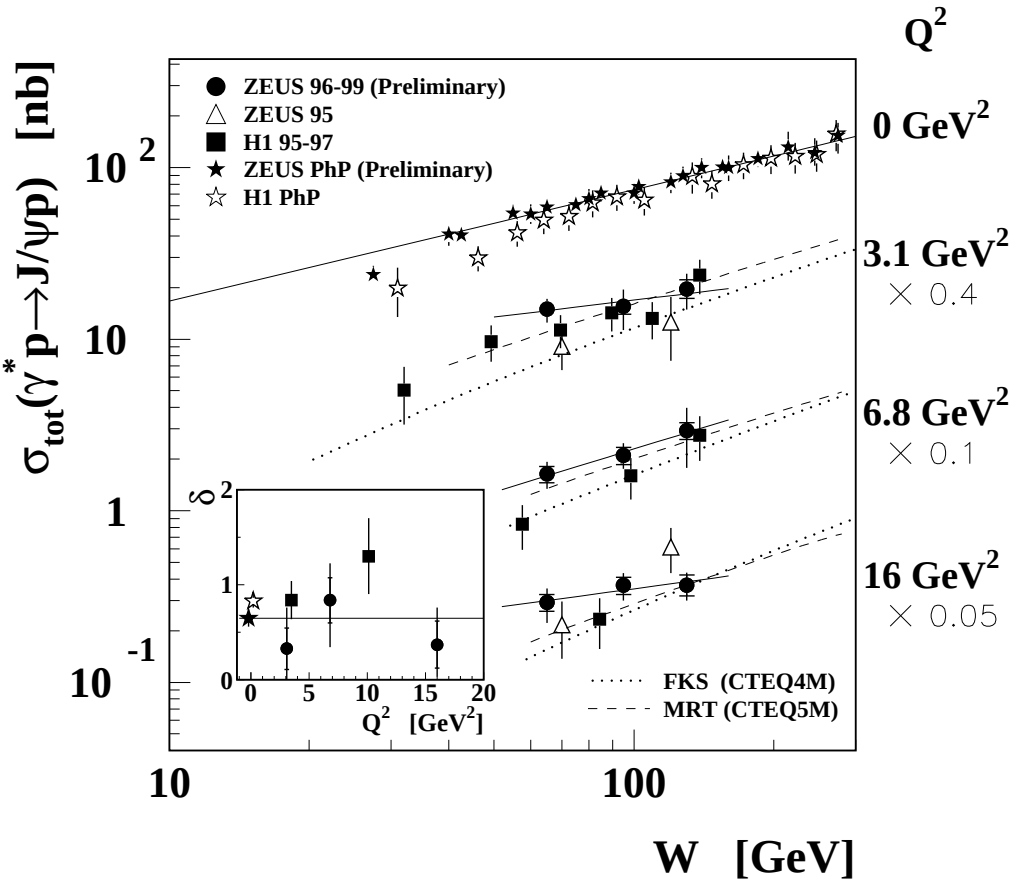

FIGURE 1. W-dependence of the cross section. The H1 cross sections at the Q^2 values, 3.5, 10.1 and 33.6 GeV^2 have been rescaled according to the Q^2-dependence from the H1 measurement. The solid lines are the results of the fit to the ZEUS data using the function W^δ. The resulting δ values for the H1 and ZEUS data are shown in the inset. The cross sections are compared with the pQCD-based calculations from Frankfurt et al. (FKS) using CTEQ4M and from Martin et al. (MRT) using CTEQ5M.

Q^2-DEPENDENCE

The Q^2-dependence of the cross section at $W = 90\,\mathrm{GeV}$ is shown in Figure 2. The cross sections are fitted in the range $Q^2 > 2\,\mathrm{GeV}^2$ with a simple parameterisation of $1/(Q^2 + M_{J/\psi}^2)^n$, yielding $n = 2.38 \pm 0.11$ for the H1 data and $n = 2.60 \pm 0.11(stat.)^{+0.09}_{-0.08}(syst.)$ (the solid line in Figure 2) for the ZEUS data. The extrapolation of the ZEUS fit, however, overshoots the photoproduction measurement by ZEUS [18]. The photoproduction data of H1, however, is consistent with the value extrapolated from the fit to the H1 data for $Q^2 > 2\,\mathrm{GeV}^2$. The data are also compared with the predictions from FKS using CTEQ4M and MRT using CTEQ5M and MRST99. Again the theories describe the data fairly well.

RATIO TO ρ ELECTROPRODUCTION

In VDM, the ratios of the different VM cross sections are given by the couplings of the photon to the VMs and by the elastic VM-proton cross sections. Under the simplified assumption that the photon-VM coupling is proportional to the quark-current decomposition of the photon (SU(4) flavor symmetry), and that the VM-proton cross sections are universal, the cross-section ratios are given by $\rho : \omega : \phi : J/\psi = 9 : 1 : 2 : 8$. This prediction is expected to hold in the region of $Q^2 \gg M_{VM}^2$. In the pQCD approach, this hypothesis also holds if the coupling strengths between the dipole and the two gluons, and between the dipole and the VM, are assumed to be universal.

The measured cross sections are compared with the ρ cross sections [21]. The ratio $r = \sigma_{\mathrm{tot}}^{\gamma^* p \to J/\psi p} / \sigma_{\mathrm{tot}}^{\gamma^* p \to \rho p}$ for both the H1 and ZEUS data is shown as a function of Q^2 in Figure 3. The previous ZEUS measurements in photoproduction [22] and electroproduction [12] are also shown. The value of r rises rapidly as Q^2 becomes larger. The ratio at $Q^2 = 53\,\mathrm{GeV}^2$ is consistent with the expectation from SU(4) flavor symmetry 8/9. This value of Q^2 is about five times higher than $M_{J/\psi}^2$.

POLARIZATION OF THE J/ψ

In VM production, it is possible to determine the polarization of the VM using the spin density matrix elements obtained from the angular distributions of the decay particles [24] [23]. The previous analyses of the helicity angles in both photoproduction [5–7] and electroproduction [12–14] suggest that the s-channel helicity conservation hypothesis holds to a good approximation, allowing one of the

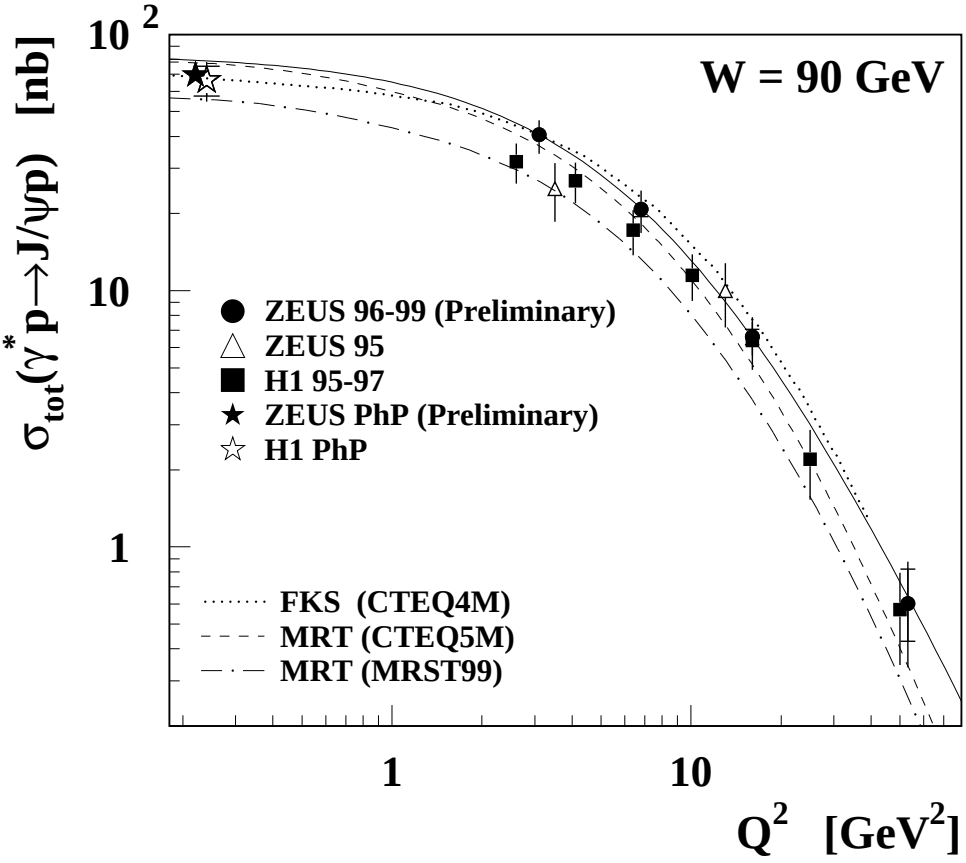

FIGURE 2. Q^2-dependence of the cross section. The solid line is a result of the fit to the ZEUS data for $Q^2 > 3\,\mathrm{GeV}^2$ using the form $1/(Q^2 + M^2_{J/\psi})^n$. The data are compared with the predictions from FKS using CTEQ4M and MRT using CTEQ5M and MRST99.

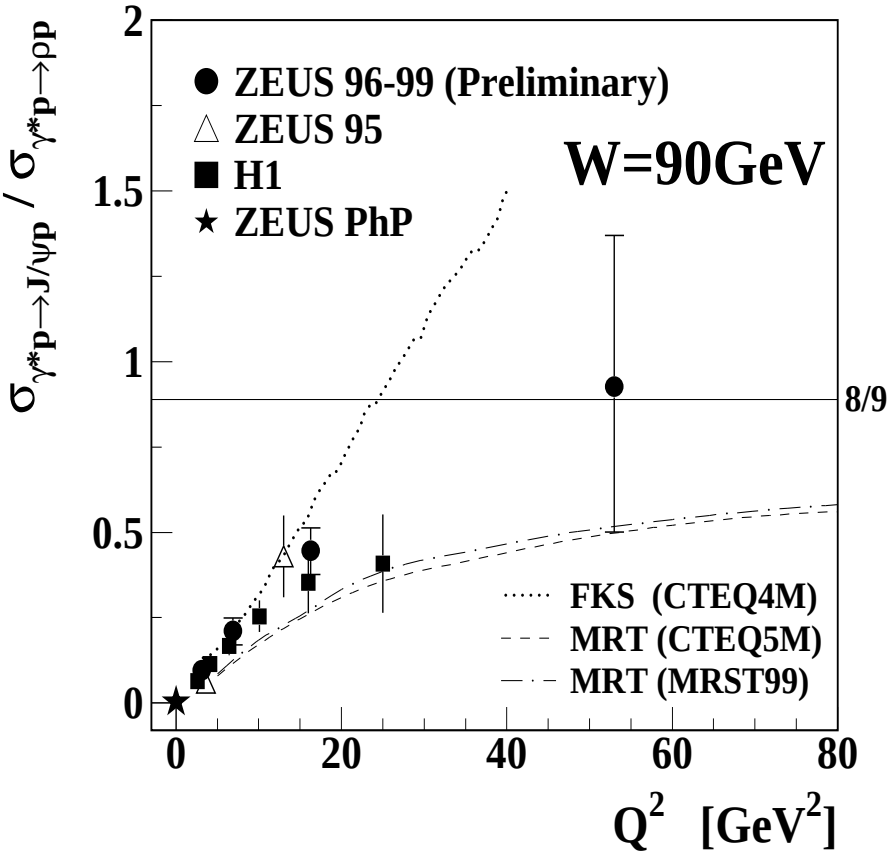

FIGURE 3. The ratio of the J/ψ to ρ cross sections as a function of Q^2. The previous ZEUS measurements in photoproduction and electroproduction are also shown.

density matrix elements (r_{00}^{04}) to be related directly to the ratio of the longitudinal to transverse cross sections ($R = \sigma_L/\sigma_T$);

$$R = \frac{r_{00}^{04}}{\epsilon(1 - r_{00}^{04})}$$

where ϵ is the ratio of the longitudinal to transverse fluxes of γ^*, $\epsilon = \Gamma_L/\Gamma_T \sim 1$. The matrix element r_{00}^{04} is determined from the distribution of the helicity angle (θ_h);

$$\frac{d\sigma}{d\cos\theta_h} \propto 1 + r_{00}^{04} + (1 - 3r_{00}^{04})\cos^2\theta_h.$$

The ratio R has been measured by fitting the $\cos\theta_h$ distribution. H1 obtained $R = 0.18^{+0.18}_{-0.14}$, $0.94^{+0.79}_{-0.43}$ at $Q^2 = 4,\ 16\,\mathrm{GeV}^2$, respectively, and ZEUS $R = -0.06^{+0.23}_{-0.09}$, $0.08^{+0.17}_{-0.14}$, $1.49^{+1.54}_{-0.83}$ at $Q^2 = 3.1,\ 6.8,\ 16\,\mathrm{GeV}^2$, respectively. The value of R increases with Q^2. The values are about one order of magnitude smaller than those measured in ρ production at the same Q^2 [12,13,21]. However, the measured values are consistent with the fitted parameterisation of R for ρ [21] replacing the ρ mass by the J/ψ one.

CONCLUSIONS

Exclusive J/ψ electroproduction has been studied at HERA by both H1 and ZEUS. W-slopes of the cross sections have been measured and found to be consistent with that of photoproduction and also with the pQCD-based calculations. The Q^2-dependence is fairly well-described by pQCD. The ratio to ρ production rises with Q^2 and is consistent with the SU(4) expectation (8/9) at $Q^2 = 53\,\mathrm{GeV}^2$. The ratio $R = \sigma_L/\sigma_T$ also rises with Q^2. Although the measured values of R are about one order of magnitude smaller than those for ρ production, they are consistent with the fitted parameterisation of R for ρ when the ρ mass is replaced by that of the J/ψ.

REFERENCES

1. R.M. Egloff et al., Phys. Rev. Lett. 43 (1979) 657.
2. R.M. Egloff et al., Phys. Rev. Lett. 43 (1979) 1545.
3. D. Aston et al., Nucl. Phys. B 209 (1982) 56.

4. J. Busenitz et al., Phys. Rev. D 40 (1989) 1.
5. ZEUS Collaboration, M. Derrick et al., Z. Phys. C 69 (1995) 39.
6. H1 Collaboration, S. Aid et al., Nucl. Phys. B 463 (1996) 3.
7. ZEUS Collaboration, M. Derrick et al., Z. Phys. C 73 (1997) 253.
8. ZEUS Collaboration, J. Breitweg et al., Eur. Phys. J. C 2 (1998) 247.
9. ZEUS Collaboration, M. Derrick et al., Z. Phys. C 73 (1996) 73.
10. ZEUS Collaboration, M. Derrick et al., Phys. Lett. B 377 (1996) 259.
11. A. Savin, Study of exclusive photoproduction of J/ψ mesons in ep interactions, these proceedings.
12. ZEUS Collaboration, J. Breitweg et al., Eur. Phys. J. C 6 (1999) 603.
13. H1 Collaboration, C. Adloff et al., Eur. Phys. J. C 13 (2000) 371.
14. ZEUS Collaboration, J. Breitweg et al., Eur. Phys. J. C 12 (2000) 393.
15. H1 Collaboration, C. Adloff et al., Eur. Phys. J. C 10 (1999) 373.
16. ZEUS Collaboration, Paper contribution to XXXth International Conference on High Energy Physics ICHEP2000, Osaka, Japan, Paper 438.
17. H1 Collaboration, C. Adloff et al., Phys. Lett. B 483 (2000) 23.
18. ZEUS Collaboration, Paper contribution to XXXth International Conference on High Energy Physics ICHEP2000, Osaka, Japan, Paper 437.
19. L. Frankfurt, W. Koepf and M. Strikman, Phys. Rev. D 57 (1998) 512.
20. A.D. Martin, M.G. Ryskin and T. Teubner, Phys. Rev. D 62 (2000) 014022.
21. ZEUS Collaboration, Paper contribution to XXXth International Conference on High Energy Physics ICHEP2000, Osaka, Japan, Paper 439.
22. ZEUS Collaboration, J. Breitweg et al., Z. Phys. C 75 (1997) 215.
23. K. Schilling and G. Wolf, Nucl. Phys. B61 (1973) 381-413.
24. H1 Collaboration, C. Adloff et al., Phys. Lett. B 483 (2000) 360-372.