Diffractive Heavy Vector Meson Production at HERA

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Selected recent results from the HERA experiment H1 on diffractive J/ψ and $\psi(2S)$ electroproduction in ep collisions are reviewed [1]. The topics covered are J/ψ cross sections as a function of the hadronic centre of mass energy W and of the four-momentum transfer Q^2. The corrected $|t|$ distribution for J/ψ mesons together with the extraction of the elastic slope parameter b is shown as well as a study of the helicity structure through decay angular distributions. Finally, the Q^2 dependence of the cross section ratio of $\psi(2S)$ to J/ψ will be presented.

1. Elastic J/ψ Production

In order to reconstruct J/ψ mesons the leptonic decay modes $J/\psi \to \mu\mu$ and $J/\psi \to ee$ are analysed. With help of the instrumentation in forward (proton) direction elastically scattered J/ψ mesons are well separated from those with proton dissociation (tagging down to $M_Y \sim 1.6\,\mathrm{GeV}$ [2]). The data are corrected for backgrounds from proton dissociation ($\sim 15\,\%$), non-resonant QED two-photon processes ($12\pm3\%$) and from the process $\psi(2S) \to J/\psi + \text{neutrals}$ (see section 1.5).

The systematic error of the cross section, which is dominated by the unfolding of the elastic and the proton dissociative production as well as by the lepton identification, is estimated to 17 %.

The data correspond to an integrated luminosity of about $\int \mathcal{L}\,\mathrm{dt} \approx 27\ \mathrm{pb}^{-1}$ and cover the following, with respect to previous analyses extended kinematic range: $2 < Q^2 < 80\,\mathrm{GeV}^2$ and $25 < W < 160\,\mathrm{GeV}$.

1.1. W Dependence of the Cross Section

The total $\gamma^* p$ cross sections for the entire W region are shown in Fig. 1 as a function of W in three bins of Q^2 together with measurements of the ZEUS collaboration [3] at similar values of Q^2. Fits of the form $\sigma_{\gamma^* p} \propto W^{\delta}$ are performed at the different Q^2 values to the H1 data alone. The obtained values for δ are well compatible with that previously found in quasi-real photoproduction at HERA (also shown in Fig. 1). A fit to H1 and ZEUS data in photoproduction yielded $\delta = 0.80 \pm 0.10$ [4], while $\delta = 0.84 \pm 0.20$ at $Q^2 = 3.5\,\mathrm{GeV}^2$ and $\delta = 1.3 \pm 0.4$ at $Q^2 = 10.1\,\mathrm{GeV}^2$.

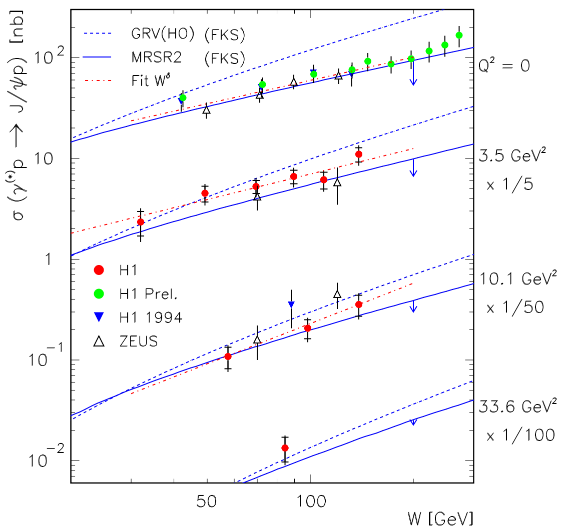

Figure 1. Total elastic J/ψ cross section $\sigma_{\gamma^* p}$ as a function of W for different Q^2 domains.

The data are also compared to the model of Frankfurt et al. [5] using different proton parameterisations (GRV(HO) and MRSR2). The latter describes the slope of the data well while GRV(HO) is too steep. The normalization of the predictions especially at low Q^2 shows the sensitivity to the choice of the charm quark mass. The arrows indicate the absolute change in $\sigma_{\gamma^* p}$ for a change of $m_c = 1.4\,\mathrm{GeV}$ up to $m_c = 1.5\,\mathrm{GeV}$.

1.2. Q^2 Dependence of the Cross Section

The Q^2 dependence of the cross section is shown in Fig. 2. It is well described by a fit $\sigma \propto (Q^2 + m_\psi{}^2)^{-n}$ with $n = 2.38 \pm 0.11$. This value of n is rather similar to those found for light vector mesons such as ϕ and ρ.

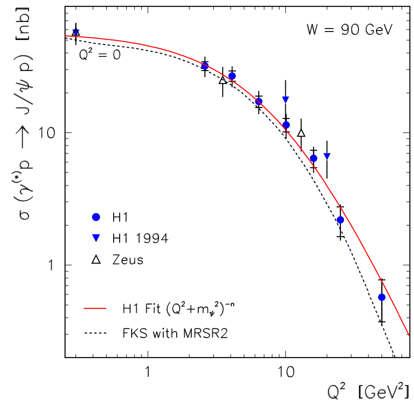

Figure 2. Total elastic J/ψ cross section $\sigma_{\gamma^* p}$ as a function of Q^2 at $W = 90$ GeV.

A hint for a steepening of the Q^2 dependence can be seen when performing the fit for low and high Q^2 separately: $n = 2.12 \pm 0.20$ for $Q^2 < 12\,\mathrm{GeV}^2$ and $n = 2.97 \pm 0.51$ for $Q^2 > 12\,\mathrm{GeV}^2$. The data are also compared to the model of Frankfurt et al. with the MRSR2 gluon distribution. Fixing the normalization to the photoproduction point ($Q^2 = 0\,\mathrm{GeV}^2$) gives a good description up to the highest accessible Q^2.

1.3. Elastic Slope Parameter *b*

The elastic slope parameter b is extracted by fitting three contributions with fixed relative normalizations to the corrected $|t|$ distribution of the elastically enriched data sample (Fig. 3).

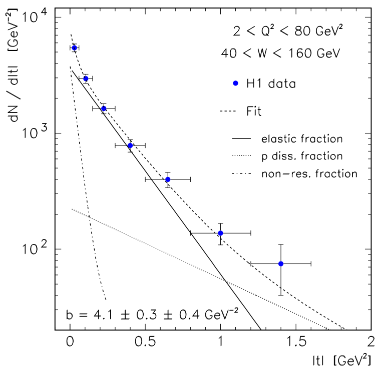

Figure 3. $|t|$ distribution of elastically enriched J/ψ events.

The fit is performed up to $|t| = 1.2\,\mathrm{GeV}^2$, taking into account 12 % non-resonant background and 13 % contribution from the proton dissociation process. Assuming a simple exponential $dN/d|t| \propto exp(-b|t|)$ for elastically scattered events yields: $b = 4.1 \pm 0.3 \pm 0.4\,\mathrm{GeV}^{-2}$ at $W = 96$ GeV and $Q^2 = 8\,\mathrm{GeV}^2$. This is found to be compatible with corresponding H1 and ZEUS results in photoproduction.

1.4. Helicity Analysis

At higher Q^2 values a finite fraction of the J/ψ mesons is longitudinally polarized. In order to investigate the helicity structure of the process angular distributions of the J/ψ decay leptons in the helicity frame [6] are measured. The $cos\theta^*$ distribution, with θ^* being the decay angle of the positive lepton with respect to the J/ψ's direction of flight, as well as the polarization angle Ψ between the positron scattering plane and the J/ψ decay plane are extracted for two different Q^2 regions (Fig. 4). No separation of elastic and proton dissociative J/ψ is performed.

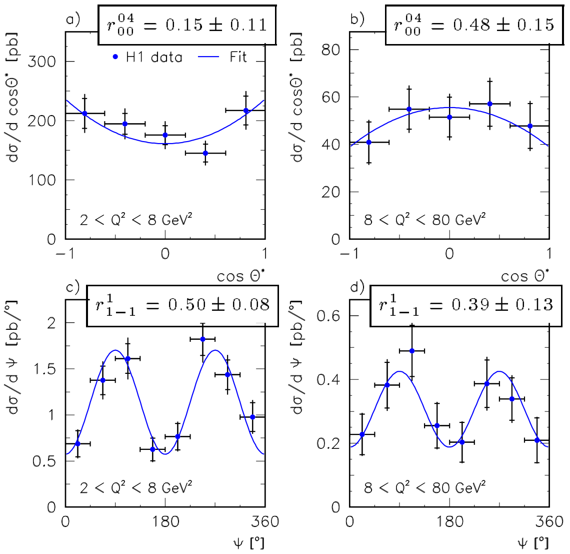

Figure 4. Helicity angular distributions of $cos\theta^*$ (a,b) and Ψ (c,d) in two Q^2 regions. The corresponding resulting spin density matrix elements are given in boxes.

Under the assumption that the helicity of the virtual photon is retained by the J/ψ meson (SCHC), The $cos\theta^*$ distribution is related to the spin density matrix element r^{04}_{00}, the probability of the J/ψ meson to be longitudinally polarized. The results for r^{04}_{00} are given in Fig. 4.a,b). The spin density matrix element r^1_{1-1} can be extracted in the two Q^2 regions from the polarization angle Ψ (see Fig. 4.c,d). On the other hand, when deriving r^1_{1-1} from the $cos\theta^*$ fit with help of the identity $r^1_{1-1} = 1/2 \cdot (1 - r^{04}_{00})$ (assuming, that only natural parity exchange NPE occurs), the derived value for r^1_{1-1} and that one from the fit to $d\sigma/d\Psi$ agree within one standard deviation, thus supporting the SCHC and NPE approximations. Due to the relation $R = \sigma_L/\sigma_T = 1/\varepsilon \cdot r^{04}_{00}/(1 - r^{04}_{00})$ (assuming SCHC and NPE), the ratio of longitudinally to transversely polarized J/ψ mesons, R, can be determined from the $cos\theta^*$ distribution in the two Q^2 regimes: $R = 0.18^{+0.18}_{-0.14}$ for $Q^2 = 4\ \mathrm{GeV}^2$ and $R = 0.94^{+0.79}_{-0.43}$ for $Q^2 = 16\ \mathrm{GeV}^2$. Using in addition the photoproduction measurements [8,9] of $R = 0.17 \pm 0.14$ and $R = -0.01 \pm 0.09$, a rise of R with increasing Q^2 can be deduced. Comparing at a scale Q^2/m_V^2, compatible results for R are found in ρ and in J/ψ production.

1.5. Diffractive $\psi(2S)$ Production

Diffractive $\psi(2S)$ production is measured via the decay channel $\psi(2S) \to J/\psi\pi^+\pi^-$, whith the J/ψ decaying into electrons or muons. The elastic and proton dissociative contributions are not separated. The kinematic region is slightly extended to $1 < Q^2 < 80\ \mathrm{GeV}^2$ and $40 < W < 180\ \mathrm{GeV}$ with respect to section 1. Systematic uncertainties, dominated by the pion and muon reconstruction, amount to 16 %. In Fig. 5 the ratio of the cross sections is displayed in three bins of Q^2.

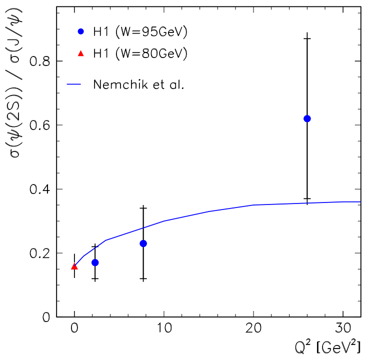

Figure 5. The ratio of $\psi(2S)$ to J/ψ production as a function of Q^2 together with a QCD prediction.

In addition a previous photoproduction measurement [10] and the prediction by Nemchik et al. [11] within a QCD model are shown. Good agreement is found between the low Q^2 bin and the photoproduction point. An indication on the level of two standard deviations is seen for a rise with Q^2, which is compatible with QCD predictions expecting an asymptotic value of the ratio of about 0.5 at $Q^2 \gg m^2_\psi$.

2. Summary and Conclusions

New precise data from the H1 collaboration on elastic J/ψ electroproduction are presented. Comparisons of cross sections as functions of W and Q^2 with perturbative QCD models show a reasonable description. The elastic slope parameter b is found to be compatible with results from photoproduction. For J/ψ production SCHC is a good approximation, allowing the measurement of R, the ratio of longitudinal to transverse polarized J/ψ mesons. The first observation of $\psi(2S)$ in DIS at HERA is reported. The measured cross section ratio of $\psi(2S)$ to J/ψ is found to rise with Q^2 as expected by QCD models.

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