EPS-0469
Submitted to Pa 14 and Pl 3,4,11

J/ψ Meson Production in Deep Inelastic Scattering at HERA

H1 Collaboration

Abstract

Results are presented on J/ψ production in electron–proton scattering using data taken in 1994 with the H1 detector at the ep collider HERA. The J/ψ mesons are detected via their leptonic decay modes to electrons and muons. The $\gamma^* p$ cross section is determined for quasi-elastic J/ψ production at an average $Q^2 = 18\,\mathrm{GeV}^2$ and $W_{\gamma p} = 70\,\mathrm{GeV}$. The cross section is found to be large compared to data at low energy. It is of the same order of magnitude as elastic ρ production at similar Q^2 and $W_{\gamma p}$.

J/ψ production in electron–proton scattering at HERA has recently been studied in the photoproduction regime ($Q^2 \to 0$) [1, 2, 3]. Here we present first results on quasi–elastic J/ψ production at finite values of the photon virtuality Q^2, where the term quasi–elastic comprises elastic processes in which the proton remains intact, and proton–inelastic processes where the proton dissociates.

Traditionally such processes have been described using the generalized Vector Meson Dominance Model (GVDM) [4], but recently models based on perturbative QCD have been proposed [5, 6].

Event selection

The data presented are based on an integrated luminosity of $2.8\,\mathrm{pb}^{-1}$ and were taken in 1994 at HERA with energies of 27.6 GeV and 820 GeV for the positron and proton beam respectively.

The event-selection requires the scattered electron to be registered in the H1 detector [7] with an energy above 10 GeV and a polar angle (with respect to the proton direction) $\theta_e < 173.5°$. Cuts are applied to ensure a precise electron measurement [8]. The J/ψ mesons are detected via their leptonic decay modes to e^+e^- and $\mu^+\mu^-$ where no particle identification is applied. The events are required to contain, in addition to the scattered electron, exactly two tracks fitted to the primary event vertex, with momenta $p > 0.8\,\mathrm{GeV}$ and polar angles $20° < \theta < 160°$. To reduce the contribution of inelastic J/ψ production, a cut on the inelasticity $z = \frac{P \cdot p_\psi}{P \cdot p_q} > 0.95$ is applied, where P, p_ψ and p_q are the four vectors of the incoming proton, the J/ψ and the exchanged photon.

The sample contains a significant proportion of events in which the proton dissociates, which is estimated to be $50 \pm 10\,\%$. This estimate is based on Monte Carlo calculations (DIFFVM [9] with an equal proportion of elastic and proton–inelastic events) and checked experimentally by analysing signals in detector components in the forward region ($\theta < 17°$) with the method described in [1].

The mass spectrum of the track pairs, assuming that the particles are muons, is shown in figure 1. A clear J/ψ signal is observed.

Results

In an interval of ± 200 MeV around the nominal J/ψ mass 43 events above a background of 9 are observed.

In order to calculate a cross section, the detector acceptance and selection efficiencies are determined by Monte Carlo techniques using the generator DIFFVM which includes elastic and proton–inelastic J/ψ production via a diffraction mechanism, and describes the data well. The total detector acceptance and selection efficiency ranges from 35 % to 64 % in the kinematical region covered.

The kinematics are calculated using quantities both from the reconstruction of the scattered electron and the hadronic final state. Q^2 is determined from the scattered electron as

$$Q^2 = 4 \cdot E_e \cdot E_{e'} \cdot \cos^2 \frac{\theta_e}{2} \ , \qquad (1)$$

	Q_0^2 [GeV^2]	30 GeV $< W <$ 150 GeV # events	$\sigma_{ep\to J/\psi X}$ [pb]
8 GeV$^2 < Q^2 <$ 19 GeV^2	12	26	143±28
19 GeV$^2 < Q^2 <$ 30 GeV^2	24	10	41±13
30 GeV$^2 < Q^2 <$ 41 GeV^2	35	6	32±13

Table 1: Event numbers and ep cross sections (preliminary). The quoted errors are statistical only. Systematic errors are estimated to be below 20 %.

with E_e and $E_{e'}$ being the energy of the incoming and scattered electron, whereas y is reconstructed from the hadronic final state [11]:

$$y = \frac{\sum(E_i - p_{z,i})}{2E_e} \ . \qquad (2)$$

The photon-proton center-of-mass energy $W_{\gamma p}$ is given by

$$W_{\gamma p}^2 = y \cdot s + m_p^2 - Q^2 \ . \qquad (3)$$

The resulting ep cross section is shown in three Q^2–bins in table 1. A J/ψ branching ratio into two leptons of 0.12 was taken into account. Systematic errors come mainly from the background subtraction and are estimated to be below 20 %.

The ep cross section can be converted to a $\gamma^* p$ cross section using the following relationship:

$$\frac{d^2\sigma^{ep}}{dQ^2\,dy} = f^T_{\gamma^*/e} \cdot \sigma^T_{\gamma^* p} \cdot (1 + \eta\, R) \ . \qquad (4)$$

Here the flux of transverse photons $f^T_{\gamma^*/e}$ is calculated according to [10], $\eta = f^L_{\gamma^*/e}/f^T_{\gamma^*/e} \approx 1$ in the acceptance region ($y < 0.25$) and $R = \sigma^L_{\gamma^* p}/\sigma^T_{\gamma^* p}$.

As the data span a large range in Q^2 and $W_{\gamma p}$, a model has to be assumed to calculate the weighted average of Q^2 and $W_{\gamma p}$ for each bin. We use the GVDM parametrisation, i.e. $R = \xi \frac{Q^2}{\Lambda^2}$ and $\sigma^T_{\gamma^* p} \sim \frac{1}{(Q^2+\Lambda^2)^n}$ with $\xi = 1$, $n = 2$ and $\Lambda = m_\psi$. Furthermore, the $W_{\gamma p}$ dependence is assumed to be $\sigma^T_{\gamma^* p} \sim W_{\gamma p}^{4\epsilon}$. To control the model dependence, ξ, n, Λ and ϵ are varied within wide ranges[1]. The bin center (W_0, Q_0^2) is chosen so that cross section variations due to variations of the parameters are minimized. The resulting systematic error is estimated to be less than 10 %.

The Q^2 dependence of the $\gamma^* p$ cross section for $W_0 = 70$ GeV, together with the prediction of GVDM with varying values of ξ, is shown in figure 2 (left). The cross section as a function of $W_{\gamma p}$ is shown for two $W_{\gamma p}$ bins ($30 - 90$ GeV and $90 - 150$ GeV) with $Q_0^2 = 18$ GeV^2 in the right part of figure 2. The curves are $\sim W_{\gamma p}^{4\epsilon}$ with $\epsilon = 0.25$, i.e. $\sim W_{\gamma p}$.

At $W_0 \approx 70$ GeV and $Q_0^2 = 18$ GeV^2 the $\gamma^* p$ cross section for quasi-elastic J/ψ production is of the order of 20 nb. Taking into account that there is a 50% contribution of proton dissociation, it is of the same magnitude as the elastic ρ cross section in a similar kinematic region [13]. EMC measured a cross section for quasi-elastic J/ψ production of ~ 2 nb at $W_{\gamma p} \approx 15$ GeV and $Q^2 \approx 20$ GeV^2 [14].

[1] $\epsilon = 0.081$ is a fit to measurements in hadronic interactions [12]. At HERA, ϵ is known to be ≈ 0.25 for J/ψ photoproduction [1].

Summary

Quasi–elastic J/ψ meson production at $8\ \mathrm{GeV}^2 < Q^2 < 41\ \mathrm{GeV}^2$ and $y < 0.3$ has been observed in the H1 detector at HERA. The Q^2 dependence of the $\gamma^* p$ cross section for $30\ \mathrm{GeV} < W_{\gamma p} < 150\ \mathrm{GeV}$, combined with a measurement at $Q^2 \approx 0$, is steeper than expected in GVDM. The $W_{\gamma p}$ dependence is within errors compatible with the rise found at $Q^2 \approx 0$ corresponding to $W_{\gamma p}^{4\epsilon}, \epsilon = 0.25$. The absolute magnitude of the cross section is of the same order as for elastic ρ production after subtracting the contribution from proton dissociation.

Acknowledgements

We are very grateful to the HERA machine group whose outstanding efforts made this experiment possible. We acknowledge the support of the DESY technical staff. We appreciate the big effort of the engineers and technicians who constructed and maintained the detector. We thank the funding agencies for financial support of this experiment. We wish to thank the DESY directorate for the support and hospitality extended to the non–DESY members of the collaboration.

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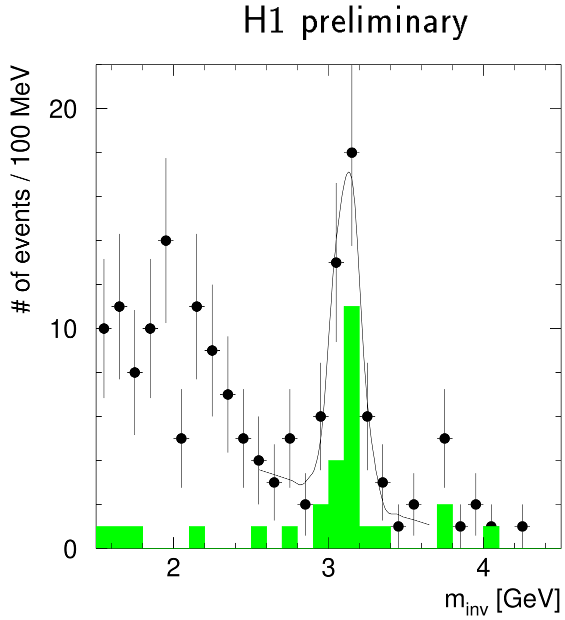

Figure 1: Mass distribution after the event selection described in the text. The curve is a fit of a Gaussian plus a linear background. The shaded histogram shows the fraction of events with at least one identified muon [1].

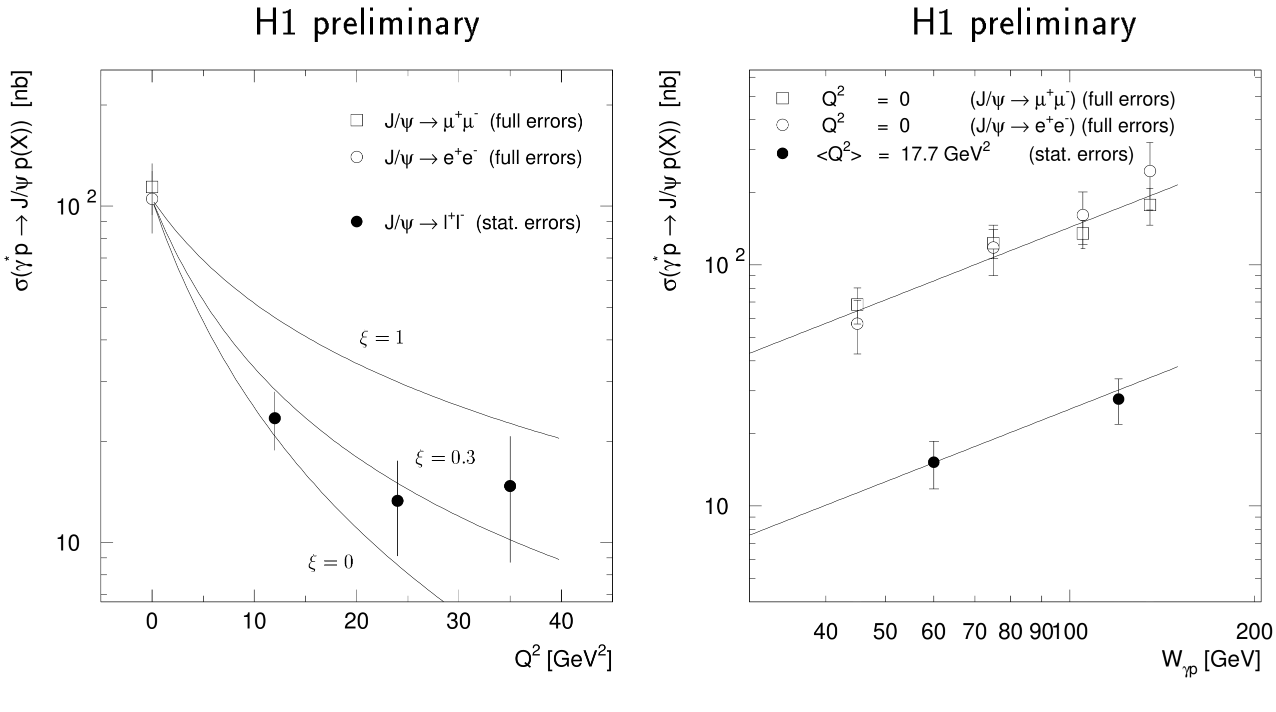

Figure 2: $\gamma^* p$ cross sections for quasi–elastic J/ψ production together with results at $Q^2 = 0$ [1].
Left: $\gamma^* p$ cross section versus Q^2 at $W_{\gamma p} = 70$ GeV. The upper curve shows the GVDM prediction with $\xi = 1$; in addition two curves with different values of ξ are included. The photoproduction result for $J/\psi \to e^+e^-$ is used for normalization.
Right: $\gamma^* p$ cross section versus $W_{\gamma p}$. The curves are $\sim W_{\gamma p}^{4\epsilon}$ with $\epsilon = 0.25$.
Errors are statistical only. Systematic errors are estimated to be less than 20%.