INELASTIC J/ψ PHOTO- AND ELECTROPRODUCTION*

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Recent results from the H1 experiment on inelastic J/ψ photo- and electroproduction in ep collisions are presented. The complete HERA I data, corresponding to an integrated luminosity of $\sim 80\,\mathrm{pb}^{-1}$, are compared to Colour Singlet Model (CSM) predictions and calculations based on non-relativistic QCD. First measurements of the polarisation of the J/ψ meson are shown.

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1. Introduction

Inelastic J/ψ production in ep collisions is dominated by the process of photon–gluon–gluon fusion where a photon from the incoming electron and a gluon from the proton produce a $c\bar{c}$ pair. This process can be calculated within the framework of Non-Relativistic QCD (NRQCD) where the cross section is a sum over all possible intermediate $c\bar{c}$ states, including Colour Singlet (CS) and also Colour Octet (CO) states. The amplitude for each $c\bar{c}$ state with definite colour and angular momentum factorises into a short distance term which can be calculated in NRQCD and a Long Distance Matrix Element (LDME) describing the transition to a J/ψ which is not calculable at present. Previous HERA measurements show good agreement with the colour singlet term alone, which is the only term taken into account in the colour singlet model, but small colour octet contributions could not be excluded. In contrast to this J/ψ production in $p\bar{p}$ collisions [1] can only be described by adding colour octet contributions.

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At HERA two kinematic domains are distinguished: in photoproduction ($Q^2 < 1\,\mathrm{GeV}^2$) the exchanged photons are quasi-real, in electroproduction they have a higher virtuality ($Q^2 > 2\,\mathrm{GeV}^2$).

2. Photoproduction

Due to the small virtuality of the exchanged photon in the photoproduction region, processes with resolved photons, predominantly gluon–gluon-fusion, are expected to contribute to inelastic J/ψ production. For these processes the elasticity z, the fractional energy transfer from the photon to the J/ψ meson, is small, while in the region of higher elasticities z the "direct" photon–gluon-fusion mechanism dominates. The data [2] are studied in two regions: "medium" elasticity defined as $0.3 < z < 0.9$, and "low" elasticity $0.05 < z < 0.45$, both restricted in the squared transverse momentum of the J/ψ meson in the laboratory system to $p^2_{\mathrm{t},\psi} > 1\,\mathrm{GeV}^2$.

2.1. Colour singlet model in NLO

Calculations in the Colour Singlet Model exist in next-to-leading order (NLO) for the direct photon–gluon-fusion process [3] and are compared to data in the "medium" elasticity range $0.3 < z < 0.9$ (Fig. 1). The CSM prediction in NLO describes well the dependences on the photon–proton center-of-mass energy $W_{\gamma p}$, the elasticity z and the squared transverse momentum $p^2_{\mathrm{t},\psi}$ of the J/ψ meson in the laboratory system, while the LO calculation is much too steep in $p^2_{\mathrm{t},\psi}$.

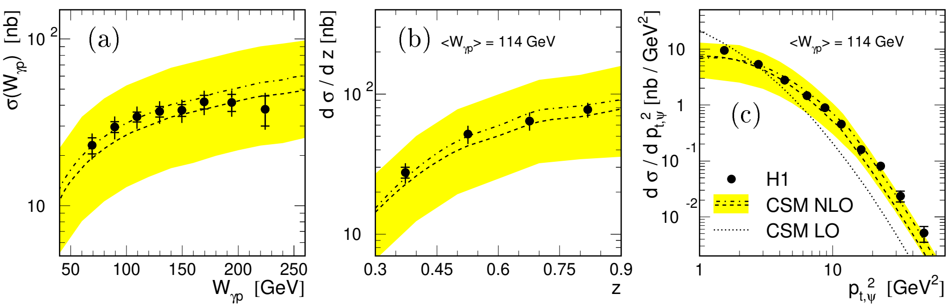

Fig. 1. (a) Total J/ψ photoproduction cross section as a function of $W_{\gamma p}$ and differential cross sections as functions of (b) $p^2_{\mathrm{t},\psi}$ and (c) z. The data are compared to CSM calculations in LO and NLO. The shaded band shows the normalisation uncertainties due to variations of α_{s} and the charm mass m_c; the dashed (dash-dotted) curve is calculated with $m_c = 1.3(1.4)\,\mathrm{GeV}$, $\alpha_{\mathrm{s}}(M_Z) = 0.1175(0.1225)$.

2.2. Non-relativistic QCD

The elasticity distribution (Fig. 2(a)) can be described in the whole range by leading order NRQCD calculations [4,5] with LDMEs for the colour octet contributions at the lower end of the range allowed by the Tevatron data. The colour singlet part alone (in LO) has problems to describe the low z region. Adding resolved contributions improves the description for both full NRQCD and the CSM.

The steeper rise of the NRQCD calculations towards high z than that in the data may be due to phase space limitations for the emission of soft gluons in the transition from the $c\bar{c}$ state to the J/ψ meson which are not considered in [4, 5]. A resummation [6] of the non-relativistic expansion, which is valid at large $p_{t,\psi}$, leads to a considerable reduction of the increase and better agreement with the data (Fig. 2(b)).

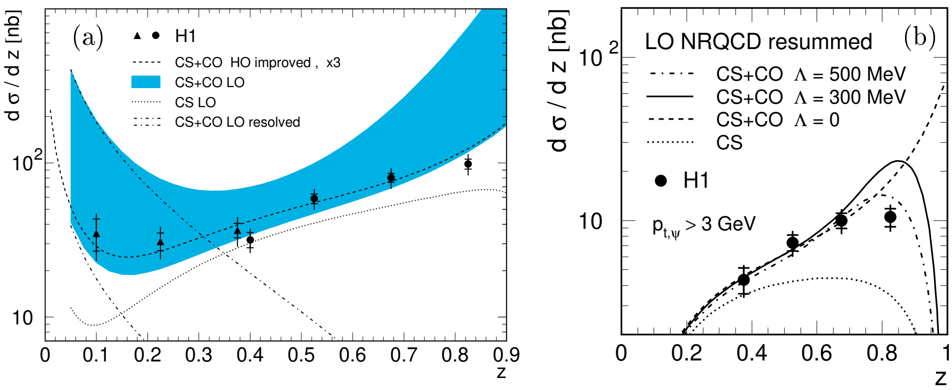

Fig. 2. (a) Differential J/ψ photoproduction cross section as a function of z for low and medium elasticities. The data are compared to NRQCD calculations [4,5]. The shaded band shows the uncertainty due to the LDMEs. (b) Differential cross section as a function of z for $p_{t,\psi} > 3\,\text{GeV}$ in comparison with a resummed NRQCD calculation [6] (scaled by a factor 3). The parameter Λ describes the energy loss of the J/ψ due to soft gluon emission.

3. Electroproduction

The inelastic electroproduction of J/ψ mesons [7] is studied in the region $2 < Q^2 < 100\,\text{GeV}^2$ for medium elasticities $0.3 < z < 0.9$. In addition the squared transverse momentum of the J/ψ meson in the photon-proton center-of-mass system is restricted to $p^{*2}_{t,\psi} > 1\,\text{GeV}^2$. Neither the full NRQCD calculation [8] nor the colour singlet part can describe the data in normalisation (Fig. 3(a), (b)). At high Q^2 and $p^{*2}_{t,\psi}$, where the theoretical

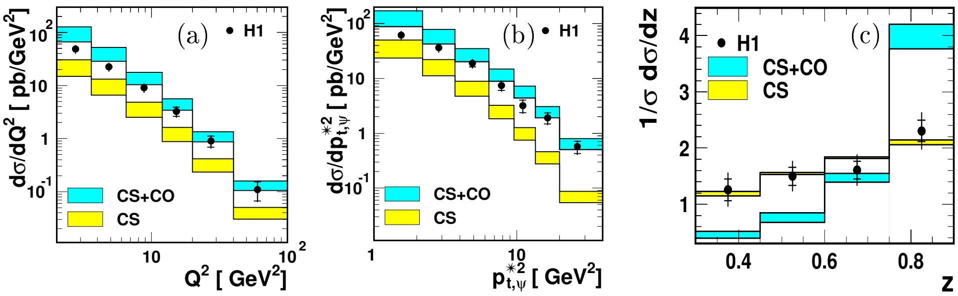

Fig. 3. Differential J/ψ electroproduction cross section as a function of (a) Q^2 and (b) $p^{*2}_{\mathrm{t},\psi}$. (c) Normalised differential cross section as a function of z. The data are compared to a full NRQCD calculation [8] (dark grey) and to the colour singlet contribution alone (light grey). The bands show the theoretical uncertainties.

uncertainties are expected to be smaller, agreement with the full NRQCD prediction is found. The CSM prediction falls too steeply in $p^{*2}_{\mathrm{t},\psi}$. This may be due to missing higher order contributions in this LO calculation (*cf.* Fig. 1(c) in photoproduction). The dependence of the cross section on z, however, is well described by the CS contribution, while the calculation including the CO contributions rises too strongly towards large z. Once again this may be due to phase space limitations for the emission of soft gluons.

4. Polarisation

The polarisation of the J/ψ meson offers the possibility to study its production mechanism without normalisation uncertainties. The polarisation parameter λ is extracted from a fit of the form $\mathrm{d}\sigma/\mathrm{d}\cos\theta^* \propto 1 + \lambda\cos^2\theta^*$ to the dependence of the cross section on θ^*, the polar angle of the positive decay lepton in the J/ψ rest system. The cases $\lambda = 1$ and -1 correspond to transverse and longitudinal polarisation of the J/ψ meson, respectively.

In electroproduction (Fig. 4(a)) a value $\lambda = -0.1^{+0.4}_{-0.3}$ compatible with unpolarised J/ψ mesons and also compatible with the prediction of a k_t factorisation approach [9] is found. This approach takes only CS states into account, but ascribes intrinsic transverse momentum to the gluons inside the proton. In photoproduction positive values for λ are preferred (Fig. 4(b), (c)). The decrease of λ with increasing z is neither predicted by the NRQCD calculations [10] nor by the calculation based on a k_t factorisation approach [9], while a decrease with $p_{\mathrm{t},\psi}$ is expected for the k_t factorisation approach. The errors in the data preclude any firm conclusions.

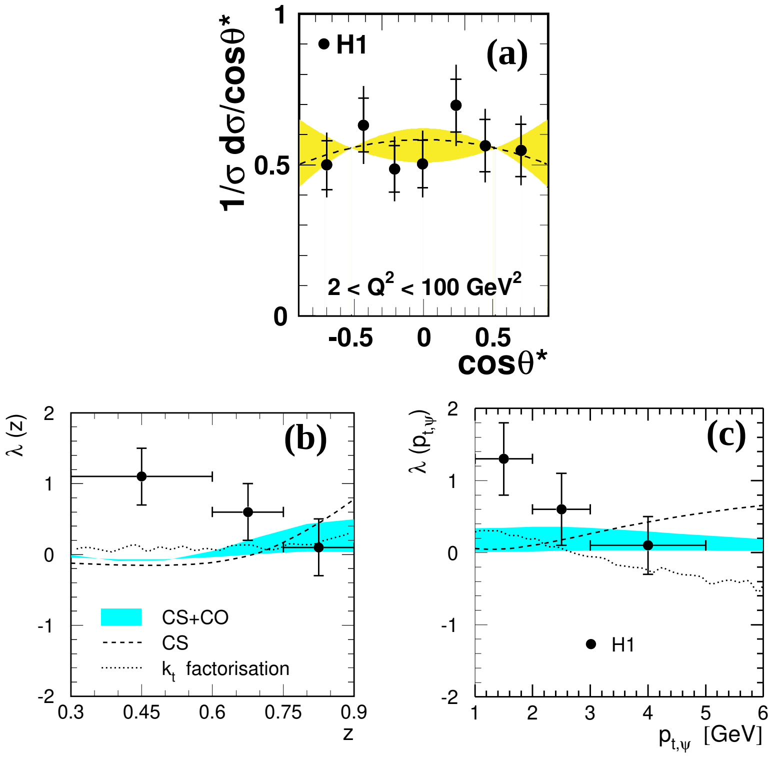

Fig. 4. (a) Normalised differential cross section as a function of θ^* in electroproduction. The light grey band shows the 1σ region of a fit to the data (see text), the dashed line the prediction of a k_{t} factorisation approach [9]. Polarisation parameter λ as a function of (b) z and (c) $p_{\mathrm{t},\psi}$ in photoproduction. The data are compared to NRQCD calculations [10] (dashed line, grey band) and the prediction of a k_{t} factorisation approach [9].

5. Summary and conclusions

New results of the H1 collaboration on inelastic J/ψ photo- and electroproduction were presented and compared to predictions in the colour singlet model and calculations based on non-relativistic QCD. In photoproduction agreement is found with the CSM in next-to-leading order and NRQCD calculations with small colour octet contributions. In electroproduction the CSM in leading order cannot describe the normalisation and the Q^2 and $p^{*2}_{\mathrm{t},\psi}$ dependences. The full NRQCD calculation is in agreement with the data at large Q^2 and $p^{*2}_{\mathrm{t},\psi}$, but fails to describe the elasticity distribution. Polarisation measurements provide information on the J/ψ production mechanism independent of normalisation uncertainties, but the present uncertainties in the data prevent any firm conclusions.

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