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Inelastic Photoproduction of J/ψ Mesons at low z

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Abstract

A measurement of the inelastic J/ψ photoproduction cross section for $z < 0.45$ via the decay $J/\psi \to \mu^+\mu^-$ is presented. In this domain, the contribution of resolved photon processes is expected to dominate. The photoproduction cross section is measured as a function of $W_{\gamma p}$ and differential cross sections are extracted as functions of $p_{t,\psi}^2$ and z. The kinematic region covered is $Q^2 < 1$ GeV^2, $130 < W_{\gamma p} < 250$ GeV and $p_{t,\psi}^2 > 1$ GeV^2. A QCD calculation involving colour singlet and colour octet contributions is compared with the measurements.

Abstract: 988, 989
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Introduction

The inelastic production of J/ψ mesons at HERA, $ep \rightarrow eJ/\psi X$, is dominated by photon gluon fusion. Calculations for the direct process in the colour singlet model [1] are available in next to leading order (NLO) [2] and are found to describe the data well in an intermediate z-region: $0.3 < z < 0.9$. On the basis of results from CDF, large additional colour octet contributions were predicted for the highest values of z, the energy of the J/ψ meson relative to the exchanged photon in the proton rest system. Such contributions could not be confirmed experimentally at HERA [3, 4]. Since these predictions were based on the theoretically very attractive non–relativistic QCD approach, many subsequent theoretical investigations have tried to find a reason for this discrepancy[1]. Discussions have included smaller octet matrix elements [6], transverse momentum effects [7] or resummations of higher orders leading to shape functions [5]. Alternatively, solutions without any colour octet contributions have been proposed [8].

The present analysis addresses lower z values[2]: $0 < z < 0.45$, where significant contributions from resolved photon processes are expected. This region is interesting in view of the large contributions from colour octet processes expected in this domain [6, 9]. Due to the limited acceptance of the H1 tracking detectors the analysis of J/ψ mesons at lower z values implies a shifted region of the photon proton center of mass energy $W_{\gamma p}$: $130 < W_{\gamma p} < 250$ GeV.

Data Analysis and Results

Data collected with the H1 detector in 1996 and 1997, when HERA collided 27.6 GeV positrons with 820 GeV protons, with an integrated luminosity of $\mathcal{L} = 24.1$ pb^{-1} are used for this analysis. The data selection proceeds in close analogy to previous H1 analyses [3]. Photoproduction events are selected by rejecting events with electromagnetic energy clusters above 8 GeV in the liquid argon or the Spacal calorimeters. This restricts the photon virtuality to $Q^2 < 1\ \mathrm{GeV}^2$. J/ψ mesons are reconstructed via their leptonic decays into muons in the central tracking chambers of the H1 detector (polar angles $20^\circ \leq \theta \leq 140^\circ$)[3]. Both tracks have to be identified as muons, at least one of them in the muon detector and the other one either in the liquid argon calorimeter of the H1 detector or in the muon detector. Inelastic J/ψ events are selected by requiring in addition to the decay leptons at least one more charged particle originating from the interaction vertex. In addition, the inelasticity z of the J/ψ meson is used. It is defined as $z = \frac{P_p \cdot P_\psi}{P_p \cdot q}$ where P_p, P_ψ and q are the four vectors of the proton, the J/ψ meson and the photon.

The resulting mass distribution of the muon pairs in the range $z < 0.45$, $130 < W_{\gamma p} < 250$ GeV and $p_{t,\psi}^2 > 1$ GeV^2 is shown in figure 1. The unlike sign muon pairs are fitted with the sum of a Gauss distribution and a linear function to parametrize the background. The number of J/ψ signal events is obtained for each analysis bin by repeating this fit, counting the number of muon pairs in the mass window $2.9 < M_{\mu\mu} < 3.3$ GeV, and subtracting the non–resonant background obtained from the linear fit.

[1] For an overview see e.g. ref. [5]

[2] Strictly speaking $z = 0$ is not accessible; the kinematical limit for z is of the order of 10^{-3}.

[3] The coordinate system of H1 defines the positive z axis to be in the direction of the incident proton beam. The polar angle θ is then defined with respect to the positive z axis.

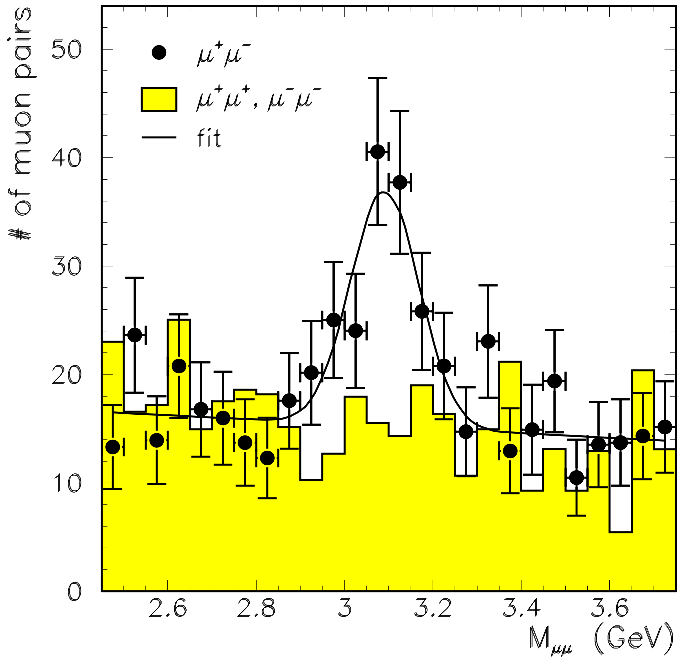

Figure 1: Mass distribution of the selected muon pairs in the range $z < 0.45$, $130 < W_{\gamma p} < 250$ GeV and $p^2_{t,\psi} > 1$ GeV^2. The unlike sign muon pairs are fitted with the sum of a Gauss distribution and a linear function to parametrize the background.

The measurement of the cross section proceeds as in ref. [3]. After correcting the observed number of events for detector acceptance and efficiencies, the ep cross section is obtained. It is converted into a γp cross section assuming factorisation of the ep reaction into emission of photons described by a photon flux and the γp interaction.

The correction of the data is performed using the Monte Carlo program EPJPSI[4] [10], generating both direct and resolved processes. The resolved process is dominated by gluon gluon fusion; quark initiated processes are neglected as are contributions from cascade decays via χ_c states. For the direct boson gluon fusion process the $p^2_{t,\psi}$ distribution is reweighted according to an exponential which was determined from the data for $0.3 < z < 0.9$, $p^2_{t,\psi} > 1$ GeV^2 and $60 < W_{\gamma p} < 180$ GeV. In this kinematic region, the normalization factor of the direct boson gluon fusion MC is determined. The resolved part is added to match the total number of J/ψ mesons for $z < 0.45$.

All efficiencies are determined using this Monte Carlo mixture. The efficiency of the lepton identification and the trigger was checked and adjusted to data using independent subtriggers. The remaining differences between data and MC are used as systematic errors. The background,

[4]The following parameters were used: $\alpha_s = 0.3$, J/ψ wave function calculated from the measured leptonic decay width Γ_{ee} including QCD corrections, MRSA' [11] for the gluon density in the proton, GRV-LO [12] for the photon, the scale in both cases is $M^2_{J/\psi}$.

originating from proton dissociative production of J/ψ and $\psi(2s)$ and from the decays of B mesons, is found to be negligible. The total systematic error is of the order of 20%. In the lowest z bin, where the background is highest, the error was enlarged to cover possible fluctuations.

The cross sections are presented in figure 2 as functions of $W_{\gamma p}$, $p_{t,\psi}^2$ and z. For comparison the prediction of the colour singlet model, as calculated in leading order in the Monte Carlo generator EPJPSI in the corresponding ditributions, is shown. The $W_{\gamma p}$ distribution (fig. 2a) shows that, with a k-factor of 2, the direct boson gluon fusion MC still lies below the data. The difference can be explained by resolved processes which mainly contribute at $z < 0.15$ (fig. 2c). The dependence of the cross section on $p_{t,\psi}^2$ (fig. 2b) agrees within errors with the power law obtained from the medium z data (see insert). In fig. 2d the z dependence is compared with a theoretical calculation [6] including colour singlet (CSM) and colour octet (COM) contributions and taking into account higher order corrections approximately for the colour octet matrix elements. A k-factor of 3 as suggested by the authors was applied. Within errors the data are compatible with the sum of the terms as well as with the colour singlet contribution alone.

Conclusion

Photoproduction of J/ψ mesons has been measured in extremely inelastic events: $z < 0.45$. The measured cross section is larger than the contribution expected from direct processes alone. The data can however be explained by contributions from resolved and direct processes. Experimental and theoretical uncertainties do not yet allow a firm conclusion concerning the presence of colour octet contributions.

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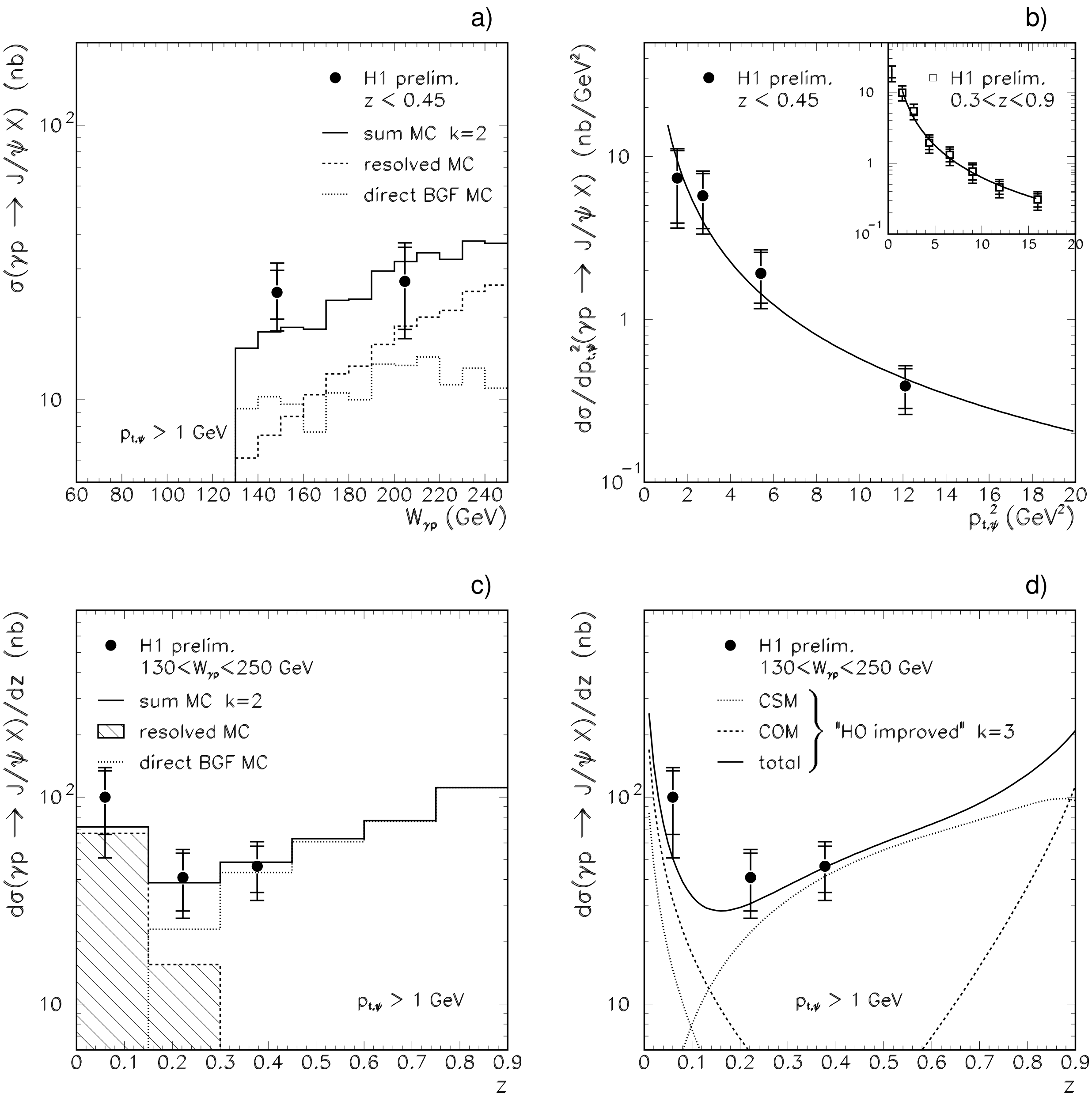

Figure 2: a) Total photoproduction cross section for inelastic J/ψ production for $z < 0.45$ and $p_{t,\psi}^2 > 1\ \mathrm{GeV}^2$. The inner error bars are statistical, the outer include statistical and systematic uncertainties added in quadrature. The histograms represent results from the LO Monte Carlo program EPJPSI (a k-factor of 2 was applied to all distributions). b) Differential cross section $\mathrm{d}\sigma_{\gamma p}/\mathrm{d}p_{t,\psi}^2$ with $z < 0.45$ integrated over $130 < W < 250\,\mathrm{GeV}$. For comparison a fit to the distribution in the range $0.3 < z < 0.9$ (see insert) is shown. c) $\mathrm{d}\sigma_{\gamma p}/\mathrm{d}z$ with a cut $p_{t,\psi}^2 > 1\ \mathrm{GeV}^2$. d) $\mathrm{d}\sigma_{\gamma p}/\mathrm{d}z$ compared with a theoretical prediction [6] including colour singlet (CSM) and colour octet (COM) contributions and taking into account higher order corrections approximately for the colour octet matrix elements. A k-factor of 3 as suggested by the authors was applied.