Elastic and Inelastic Production of J/Ψ Mesons at HERA

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Abstract. Results obtained for the production of J/Ψ mesons in photoproduction using the H1 detector at HERA are presented. The photoproduction cross section for elastic J/Ψ meson production is observed to rise with the center of mass energy, exeeding the expectations of diffractive models based on soft pomeron exchange. This rise can be described by QCD inspired models if a rise in the gluon density is assumed. For inelastic J/Ψ production the cross section is compared to NLO QCD calculations in a colour singlet model and agreement is found.

INTRODUCTION

The investigation of the production of heavy quarkonia by real or virtual photons can be considered as a probe of strong interaction physics in a region of phase space which is characterised by a transition between the regime of perturbative and non-perturbative QCD . Perturbation theory breaks down if long range interactions between heavy quarks and the proton dominate. The production of J/Ψ vector mesons is ideal for studying this transition regime in the charm sector.

Elastic and inelastic production of J/Ψ mesons has been studied in previous experiments at center of mass energies $W_{\gamma p} < 30\,GeV$. At the HERA collider the energy range of such measurements can be extended up to $W_{\gamma p} \approx 300\,GeV$.

At low energies, the diffractive (elastic and proton dissociative) production of vector mesons has been described within the Donnachie-Landshoff model [1]. This model is based on Regge phenomenology where the vector meson production is mediated by pomeron exchange. The important prediction of this model is a cross section proportional to $W_{\gamma p}^{\delta}$. For the so called soft-pomeron, a value $\delta = 0.32$ is expected. An alternative model suggested by Ryskin et al. [2,3] describes the interaction between proton and heavy vector meson by the exchange of a gluon ladder which can be calculated in perturbative QCD. For photoproduction processes the charm quark mass offers a hard scale. In this model the cross section is proportional to the square of the gluon density in the proton at Bjorken $x \approx m_{J/\Psi}^2/{W_{\gamma p}}^2$ and a much steeper rise with $W_{\gamma p}$ is predicted based on recent measurements of the gluon distribution in the proton.

The main inelastic J/Ψ production process is the photon gluon fusion mechanism, where the incoming positron radiates a photon which participates in the hard interaction with a gluon from the proton to form a $c\bar{c}$ pair. The hard interaction is calculable in perturbative QCD and the process is sensitive to the gluon density in the proton. In the colour-singlet model [4] a colourless J/Ψ state is achieved by emission of a further gluon. For this reaction NLO QCD predictions are available [5,6].

The colour-octet model [7,8] has received increased attention, since it has been proposed to explain the large excess of heavy quarkonia production rates observed at the TEVATRON [12]. In this model the transition from the coloured $c\bar{c}$ state produced in the hard subprocess proceeds non-perturbatively via emissions of soft gluons.

KINEMATICS

The results shown below were obtained with the H1 detector at the HERA storage ring at DESY, based on data collected in 1994 and 1995, where $E_e = 27.5\,GeV$ positrons collide with $E_p = 820\,GeV$ protons. The ep scattering process is

$$e(l) + p(p) \to e(l') + J/\Psi(p_{J/\Psi}) + X(p_X),$$

where the quantities in parantheses denote the particles' four momenta. The virtuality of the photon is given by $Q^2 = -q^2 = -(l-l')^2$. The electroproduction cross section at low Q^2 is given by the convolution of the photon flux from the electron with the γp cross section:

$$\sigma(ep \to J/\Psi X) = \int dy f_{\gamma/e} \sigma(\gamma p \to J/\Psi X).$$

The γp squared center-of-mass energy is given by $s_{\gamma p} = W_{\gamma p}^2 \approx 4E_eE_py$, with $y = \frac{q \cdot p}{l \cdot p} = \frac{E_\gamma}{E_e}$. The inelasticity variable $z = \frac{p \cdot p_{J/\Psi}}{p \cdot q}$ is utilized to separate diffractive and inelastic processes. Diffractive J/Ψ events are produced at $z \approx 1$, whereas for inelastic production, z is below 1. For diffractive J/Ψ production elastic processes are seperated from proton dissociation processes by requiring exactly 2 tracks and no further activity in the detector.

J/Ψ mesons are identified by their decays into lepton pairs (electrons or muons). Electrons are detected in the electromagnetic part of the calorimeters. Muons are measured with the muon detectors and are identified as minimum ionizing particles in the calorimeter.

INELASTIC J/Ψ PRODUCTION

Inelastic J/Ψ photoproduction candidate events are selected by a cut on the inelasticity $z < 0.8$. In addition, the cut $z > 0.45$ rejects events from resolved photon events. The final cross section values are corrected for the loss due to the lower z-cut ($\approx 20\%$) [9,10].

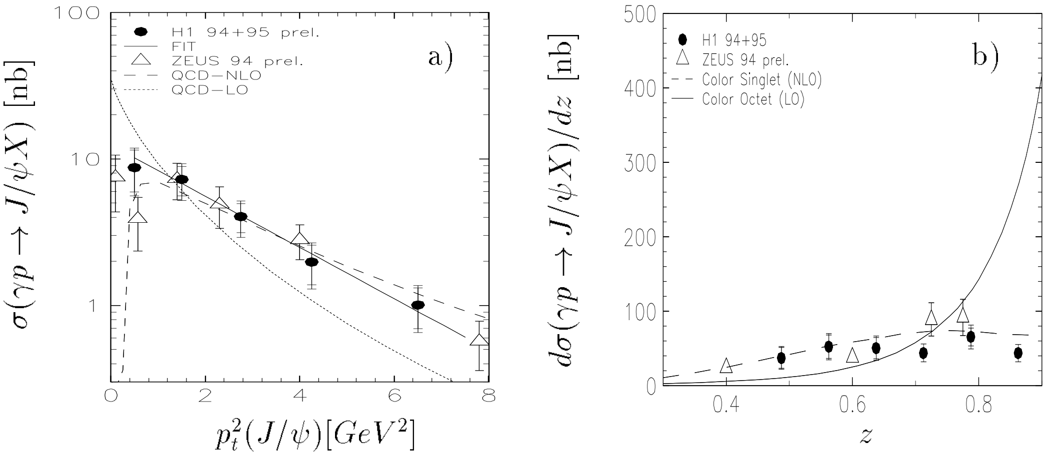

FIGURE 1. a) p_t^2 distribution of inelastically produced J/ψ mesons compared to NLO and LO QCD calculations in the colour-singlet model. b) Differential photo-production cross-section for J/ψ in the variable z, compared to predictions of the colour-singlet (NLO) and colour-octet (LO) models.

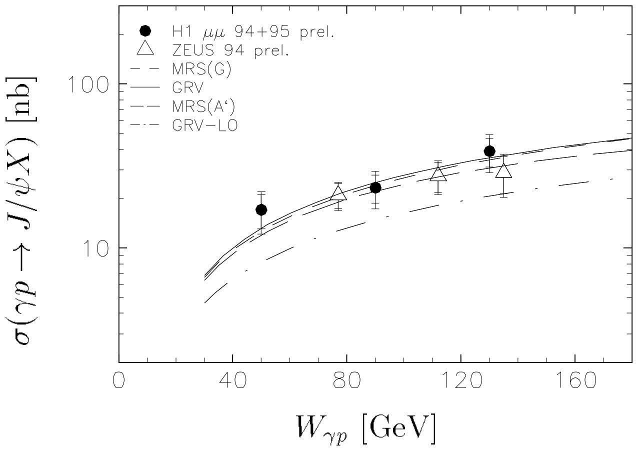

FIGURE 2. Cross-sections for inelastic photo-production of J/ψ mesons in the region $z < 0.8$, $p_t > 1\,GeV$, compared to NLO and LO QCD calculations in the colour-singlet model. Inner error bars are statistical, outer total.

The distribution of p_t^2 for inelastic J/Ψ events is shown in figure 1a. The data are well described by the prediction of the NLO QCD calculations in the colour-singlet model except at low values of p_t, where contributions of higher order become substantial. The leading order calculation, which is also shown, is much steeper than the data.

The total γp cross section for $p_t(J/\psi) > 1\,GeV$ is shown as a function of $W_{\gamma p}$ in figure 2. The prediction of the NLO QCD calculations, using a charm quark mass of $m_c = 1.4\,GeV$, a renormalisation/factorisation scale of $\mu = \sqrt{2}\,m_c$ and $\Lambda_{QCD} = 0.3\,GeV$, fit the data well in shape and in absolute normalisation. As can be seen in figure 2 the dependence of the cross section on the gluon density parameterisation is not strong with the given cuts. All gluon parametrisations which fit recent F_2 data at low x, such as GRV or MRSG or MRSA' give a good description of the data within errors.

The differential cross section $d\sigma/dz$ is also well described in the colour-singlet model (fig. 1b), but contains no indication of the sharp rise towards high z which is predicted in the colour-octet model in leading order if the long range matrix elements are chosen from fits to the TEVATRON data [8].

ELASTIC J/Ψ PRODUCTION

The elastic cross section for J/ψ [9,11] meson production as a function of $W_{\gamma p}$ is shown in figure 3a. The prediction of the Donnachie-Landshoff model does not describe the HERA data. A better description is given by the pQCD calculations of the Ryskin model using the gluon parametrisation MRS(A'). A fit of the form W^δ to the H1 data yields a value of $\delta = 0.64 \pm 0.13$.

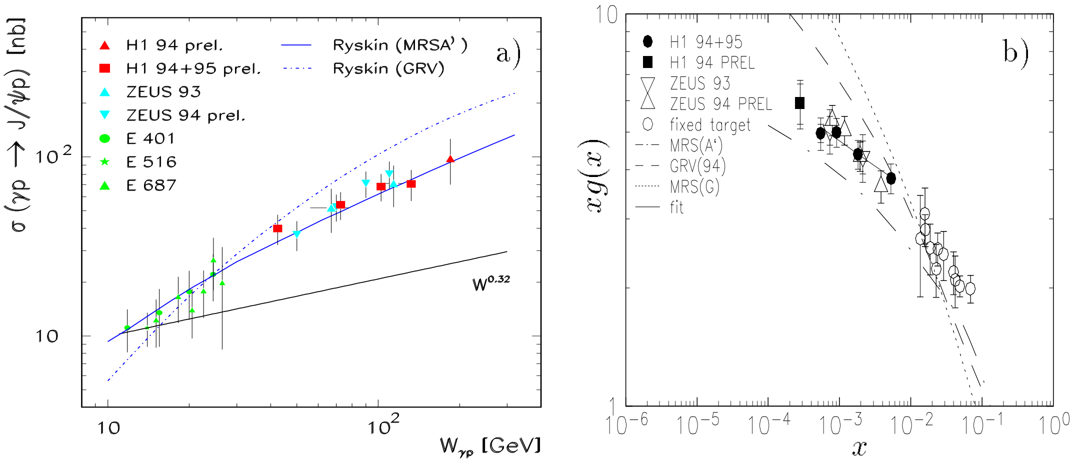

FIGURE 3. a) Total cross for elastic J/ψ production. b) Gluon density $xg(x)$ as defined in the Ryskin model obtained from elastic J/Ψ-photoproduction as function of x.

In figure 3b the measured cross sections at different values of $W_{\gamma p}$ are translated into a phenomenological gluon density $xg(x)$ as defined in the Ryskin model in leading order:

$$xg(x,\bar{Q}^2)^2 = \frac{48\alpha\bar{Q}^8}{\Gamma_{\ell\ell} m_\psi^3 \pi^3 \alpha_S^2} b \cdot \sigma(\gamma p \to \psi p) \left(1 + \frac{Q^2}{m_\psi}\right)^{-1}$$

$$with \quad x = \frac{4\bar{Q}^2}{W_{\gamma p}^2} \qquad \bar{Q}^2 = \frac{(Q^2 + m_\psi^2)}{4}.$$

The results are compared to different gluon density parametrisations. Due to an overall normalisation uncertainty of 30% one should compare only the shape of the spectra. The shape of the cross section is again well described in the Ryskin model using the MRS(A') gluon parametrisation.

CONCLUSION

Elastic J/ψ production at $Q^2 \approx 0$ shows an increase with $W_{\gamma p}$ ($30 \leq W_{\gamma p} \leq 200\,GeV$), which can be parametrisised by $W_{\gamma p}^\delta$ with $\delta = 0.64 \pm 0.13$. The flat increase with $W_{\gamma p}$ observed in hadroproduction does not describe the data. A QCD based model relating the cross section to gluon exchange successfully describes the data with current parametrizations of the gluon density.

The energy distribution of inelastically produced J/ψ mesons is well described by the colour singlet model in NLO. No indication of large octet contributions is seen within statistics. The absolute normalization between data and theory agrees within the experimental uncertainties , using a charm quark mass of $m_c = 1.4\,GeV$, $\Lambda_{QCD} = 0.3\,GeV$ and any gluon distribution which describes the F_2 data at low x.

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