Inclusive electroproduction of J/ψ mesons at HERA

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Differential Cross sections for inclusive and inelastic J/ψ electroproduction are shown in the kinematical range of $40 < W < 180\,\mathrm{GeV}$, $2 < Q^2 < 80\,\mathrm{GeV}^2$ and $0.2 < z < 1$. The results are compared to theoretical predictions of NRQCD calculations and the Monte Carlo model of soft colour interactions.

1. Introduction

In ep collisions J/ψ mesons can be produced diffractively by pomeron exchange and inelastically via boson gluon fusion. Both production mechanisms lead to different ranges in several kinematical variables. In diffraction the cross section is dominant at small $P_{t,\psi}^2$, the inelasticity z is large ($z > 0.9$) and the invariant mass M_X of the hadronic final state besides the J/ψ meson is small. On the other hand the inelastic production covers the whole z and $P_{t,\psi}^2$ range while M_X is typically large.
In the following differential cross sections for a fully inclusive J/ψ sample is presented, which contains diffractive as well as inelastic J/ψ production. In addition, results for an inelastic selection with $M_X > 10\,\mathrm{GeV}$ are shown. Both cases are compared to theoretical calculations and models. For further details see [1].

2. Theory and models

The following theoretical calculations and models of inclusive and inelastic J/ψ production will be compared to data.

Colour singlet and colour octet model

The inelastic production of J/ψ mesons is calculated in a factorization approach in the framework of non-relativistic QCD [2] (NRQCD), where colour octet states as well as colour singlet states of the intermediate $c\bar{c}$ pair contribute. In this approach the cross section for each $c\bar{c}$ state factorises into a short distance term and a long distance matrixelement which is not calculable.
Taking into account only colour singlet states of the $c\bar{c}$ pair leads to the colour singlet model that is found to be in rather good agreement with most of the HERA data [7,8]. On the other hand measurements of J/ψ production in hadronic collisions [3] have shown that the colour singlet model cannot account for the observed cross sections. These results can be described by adding colour octet states to the calculations and fitting the long range matrixelements to the data. This full calculation is often called colour octet model. LO calculations for ep collisions are available in leptoproduction [4] for both models (considered terms are $(1,^3S_1), (8,^1S_0), (8,^3P_1)$).

Soft colour interactions (SCI)

The Monte Carlo model of soft colour interactions [5] models diffractive as well as inelastic production of J/ψ mesons.
In this model coloured $c\bar{c}$ pairs are produced in a hard process via boson gluon fusion. Then additional colour interactions at a scale below the pQCD cut off are allowed. These interactions take place between the products of the hard process and the partons of the proton remnant as well as between the partons of the proton. They lead to changes of the colour topology, but not of the transverse momentum of the interacting partons. So SCI result in a modification of the hadronic final state, which means for example, that from a coloured $c\bar{c}$ pair a colourless J/ψ meson may be formed. This model is implemented, among others, in AROMA [6].

3. Dataselection and simulation

For the analyses data with an integrated luminosity of about $27.3 \pm 0.4\mathrm{pb}^{-1}$ are used. These

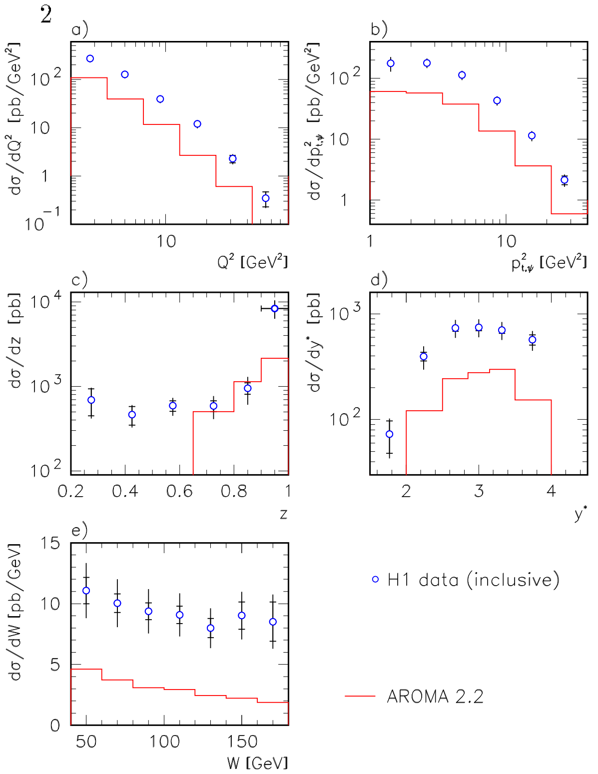

Figure 1. *Differential cross sections for inclusive (open dots) J/ψ production as a function of Q^2,$p^2_{t,\psi}$,z,y^* and W. The inner error bars give the statistical error, the outer errors are the statistical and systematical uncertainties added in quadrature. A prediction for the inclusive case is given by AROMA2.2 with SCI (dotted histogram).*

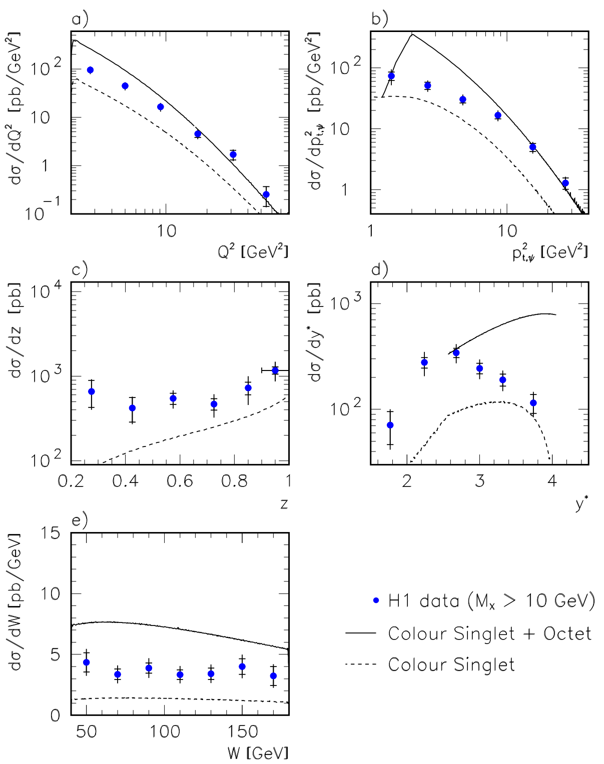

Figure 2. *Differential cross sections for inelastic (full dots) J/ψ production as a function of Q^2,$p^2_{t,\psi}$,z,y^* and W. The curves show the colour singlet model (dashed line) and the colour octet model (full line) prediction for inelastic production.*

were collected with the H1 detector in the years 1995 to 1997.

The J/ψ mesons are identified via their leptonic decay modes $J/\psi \rightarrow \mu\,\mu$ and $J/\psi \rightarrow e\,e$ with branching ratios of $6.01(6.02) \pm 0.19(0.19)\%$. The decay leptons are identified in the calorimeter (for e and μ) and in the instrumented iron (for μ) of the H1 detector. The scattered positron is detected in the backward electromagnetic calorimeter.

The results cover a kinematical range of $40 < W < 180\,\mathrm{GeV}$ and $2 < Q^2 < 80\,\mathrm{GeV}^2$ with a cut on the inelasticity $z > 0.2(0.5)$ in the muonic (electronic) decay mode.

Results for two analyses will be shown. In the inclusive case no further cut is applied. The results of inelastic J/ψ production are derived with an indirect cut on the invariant mass M_X of the hadronic final state besides the J/ψ meson by cutting on the energy in the forward part of the calorimeter $E_{fwd} > 5\,\mathrm{GeV}$. This cut is corrected to $M_X > 10\,\mathrm{GeV}$ by Monte Carlo studies.

Acceptance and efficiencies are determined using a mixture of diffractive (DIFFVM) and inelastic simulated J/ψ mesons (EPJPSI). For the right mixture EPJPSI is normalized to the data for $0.4 < z < 0.8$ and DIFFVM is added to describe the data for $z > 0.95$.

4. Results

Inclusive cross sections and SCI

Differential ep cross sections for inclusive J/ψ production are shown in figure 1 (open dots) as a

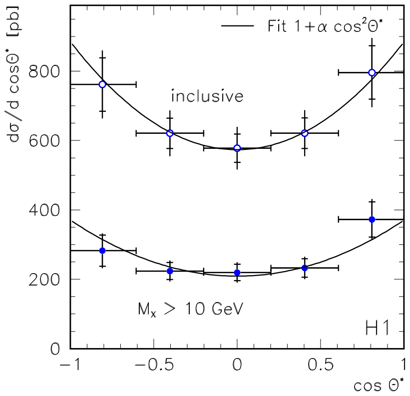

Figure 3. *Differential cross sections in* $\cos\theta^*$*.*

function of Q^2,$p_{t,\psi}^2$,z,y^* (rapidity of the J/ψ meson in the γp cms) and W. The prediction of the model of SCI (dotted histogram) is compared to these differential cross sections. Most shapes of the theoretical model are in reasonable agreement with the data, while the magnitude is too low. The z behaviour of the cross section cannot be reproduced. Due to the missing hard colour singlet contributions to the cross section in the SCI model the cross section falls below the data at low z. In addition there is a discrepancy of a factor of 4 at high z.

Inelastic cross sections and NRQCD

The differential ep cross sections for inelastic J/ψ production ($M_X > 10\,\mathrm{GeV}$) are shown in figure 2 (full dots). In comparison with the inclusive cross sections the decrease of the cross section at high z due to the applied cut can be seen. Furthermore the differences are significant in the shape of the y^* distribution. NRQCD calculations [4] are compared to the inelastic results. The colour singlet model is shown as a dashed line, the colour octet model as a full line. Both predictions fail to describe the data in magnitude (the colour singlet model is too low by a factor of 2-3) and cannot reproduce the shapes of the differential cross sections extracted from the data, especially the y^* dependence.

Decay angular distribution

The measurement of the polarisation of the J/ψ meson is interesting to distinguish different contributions to the cross section (colour singlet and colour octet terms). The decay angular distribution in the helicity frame is shown in figure 3. It

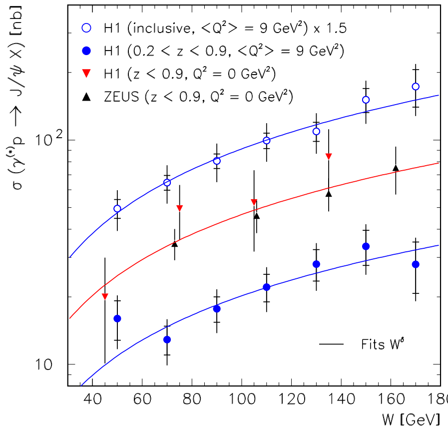

Figure 4. *Total* γp *cross section as function of* W *for inclusive and inelastic* ($z < 0.9$) J/ψ *leptoproduction and for inelastic photoproduction. The result for the inclusive analysis is multiplied by a factor of 1.5.*

is predicted to be of the form:

$$\frac{d\sigma}{d\cos\theta^*} \sim 1 + \alpha\cos^2\theta^* \ .$$

For the colour singlet model $\alpha \approx 0.5$ is expected, for the colour octet model $|\alpha| \lesssim 0.5$, negative, zero or positive depending on which term dominates. The measured values are $\alpha = 0.54^{+0.29}_{-0.26}$ for the inclusive selection and $\alpha = 0.77^{+0.44}_{-0.38}$ in the inelastic case, both compatible with the colour singlet prediction.

Comparison to photoproduction ($Q^2 \approx 0\,\mathrm{GeV}^2$) For the comparison with photoproduction the total γp cross section as function of W is calculated for the inclusive case and an inelastic selection with $z < 0.9$, the same cut as applied in photoproduction. The results are shown in figure 4 together with HERA results for $Q^2 \approx 0\,\mathrm{GeV}^2$ [7,8]. The W dependence of the cross sections is very similar for photoproduction and leptoproduction. It can be parametrised by a power law W^δ with $\delta = 0.95 \pm 0.11$, $\delta = 0.89 \pm 0.2$ and $\delta = 0.91 \pm 0.26$ for the inclusive and inelastic leptoproduction and for inelastic photoproduction.

5. Conclusion

Differential cross sections for inclusive production of J/ψ mesons in a kinematical range of

$40 < W < 180\,\mathrm{GeV}$, $2 < Q^2 < 80\,\mathrm{GeV}^2$ and $0.2 < z < 1$ have been presented and compared to the model of soft colour interactions. The shapes are in reasonable agreement with the data, while the magnitude and the z dependence cannot be reproduced.
In addition differential cross sections for inelastic J/ψ production ($M_X > 10\,\mathrm{GeV}$) have been computed and compared to calculations based on NRQCD. The colour singlet model as well as the colour octet model cannot describe the data in magnitude and in shapes. These discrepancies between data and theoretical calculation may indicate that the long distance matrixelements have to be decreased in magnitude and/or their relative importance have to be change. Also it could be necessary to include higher orders in the calculation.

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