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INELASTIC J/ψ PRODUCTION WITH ZEUS

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One of the key distributions to clarify inelastic J/ψ production mechanisms in ep collisions is the inelasticity differential cross section: in the proton rest frame, the distribution of the fraction of the virtual photon energy taken by the J/ψ. The ZEUS collaboration has measured the inelasticity differential cross section both in photoproduction and in the deep inelastic scattering regime. These measurements will be briefly described and the data compared to the available theoretical predictions. Also the analysis of the J/ψ angular distributions could be useful to probe the J/ψ production mechanisms. Current results are shortly outlined and compared to the available leading order predictions.

1 Inelasticity distribution in the photoproduction regime

Inelastic J/ψ photoproduction has been measured by both the H1 [1] and ZEUS [2] collaborations. The key variable describing the process is the inelasticity, z. In the proton rest frame z is the fraction of the virtual photon energy taken by the J/ψ. Resolved photon processes, where in the hard subprocess a parton from the photon interact with a parton from the proton, are expected to dominate at low z values, $z < 0.2$. Resolved photon contributions are expected to decrease with increasing z values. In $e\,p$ collisions at leading order (LO) only one hard subprocess can lead to a direct photon contribution: $\gamma g \rightarrow J/\psi X$, where the quasi–real photon radiated from the electron fuses with a gluon from the proton. The direct photon process is expected to be dominant for $0.2 < z < 0.9$. The production at higher z values is ascribed to diffractive processes.

The direct and resolved photon processes can be described in the colour singlet (CS) or colour octet (CO) approaches. In the CS approach, the $c\bar{c}$ pair is formed in a colour singlet state with the J/ψ quantum numbers and identified with the J/ψ physical state. In the CO approach, $c\bar{c}$ pairs produced in colour octet states could also evolve into J/ψ mesons via radiation of soft gluons. The transition of the coloured $c\bar{c}$ pairs, with given angular momentum, into J/ψ mesons is described in terms of long distance matrix elements tuned to J/ψ experimental data (hadroproduction or B–meson decay data, at present). The CO component is a consequence of non relativistic QCD theories and is needed to explain the magnitude of the J/ψ cross section measured by CDF.

A LO calculation, labelled KZSZ (LO,CS+CO), performed taking into account both direct and resolved photon contributions and summing both CS and CO terms, is compared to the HERA inelasticity data for $p_T(J/\psi) > 1$ GeV in the top left plot of Fig. 1. In the ZEUS analysis the photon proton centre–of–mass energy, W, was restricted to the range $50 < W <180$ GeV. The H1 analysis was performed in a slightly different W range and hence the final H1 results where scaled to $50 < W < 180$ GeV. The extrapolation factor was below the 5 % level. In order to enhance the acceptance at low z values the H1 collaboration also performed a measurement in the range $120 < W < 260$ GeV. In this low z range the data could also be sensitive to the resolved photon component and hence any W extrapolation will be affected by very large uncertainties. These data points, without any W extrapolation, are identified by the label "high W". The LO prediction including CS and CO contributions is consistent with the data although the measured inelasticity cross section for $z > 0.6$ is much flatter than the prediction. In the range $0.4 < z < 0.9$ the data are better described by a next–to–leading–order (NLO) calculation of the direct photon process only, performed in the limited CS framework, labelled KZSZ (NLO,CS). All predictions are affected by large theoretical uncertainties, much larger than the data uncertainties, and hence no strong conclusion can be reached.

In the top right plot of Fig. 1 the HERA inelasticity data for $p_T(J/\psi) > 2$ GeV are compared again to the NLO calculation performed in the CS framework and the agreement remains. The data are also compared to a different LO calculation of the direct photon process including both CS and CO terms, labelled BSW (LO,CS+CO). This calculation resums an infinite class of CO contributions that are important at high z, this results in a slower rise of the inelasticity cross section for $z > 0.6$ and hence in a better agreement with the data. The CS contribution alone is shown by the dotted curve labelled BSW (LO,CS).

2 Inelasticity distribution in the deep inelastic scattering regime

Compared to the photoproduction regime, inelastic J/ψ in the deep inelastic scattering regime suffers from lower statistics but, due to the non–zero photon virtuality, the non relativistic QCD theories are probed at a higher scale. The same argument is also true for the colour octet matrix elements. At non–zero photon virtuality resolved photon processes are suppressed. Hence, in the deep inelastic scattering regime, no enhancement of the inelasticity differential cross section at low z is expected.

The ZEUS inelasticity differential cross section in the deep inelastic scattering regime was measured in the phase space region defined by $2 < Q^2 < 80$ GeV^2, $50 < W < 250$ GeV and $-1.6 < y(J/\psi) < 1.3$, where Q^2 is the virtuality of the exchanged photon and $y(J/\psi)$ is the J/ψ rapidity in the laboratory frame. ZEUS measurements [3] are shown in the bottom left plot of Fig. 1. The ZEUS data points are compared to a LO prediction for the direct photon process including CS and CO or CS only matrix elements, identified by the labels KZ (CS+CO) and KZ (CS), respectively. As in the photoproduction case, the strong rise of the predicted inelasticity cross section for $z > 0.75$, due to the CO matrix elements, is not supported by the data. Predictions based on the k_T factorization approach, identified by the label LZ(kt, CS), are also shown. In this model, based on non–collinear parton dynamics governed by the BFKL evolution equations, effects due to the non–zero gluon transverse momentum are taken into account. This leads to the resummation of $\log(1/x)$ terms. The inelasticity differential cross section is calculated as the convolution of an unintegrated (transverse momentum dependent) gluon density [4] with the leading order CS off–shell matrix element (non–zero virtuality for the hard subprocess incoming gluon).

3 Angular distributions in the photoproduction regime

The J/ψ helicity distributions, namely the polar and azimuthal distributions of the J/ψ decay leptons in the J/ψ rest frame, are predicted, by the CS and CO models, to have a different dependence on the transverse momentum p_T and z of the J/ψ. Furthermore, helicity studies are mainly shape measurements; consequently they are less sensitive to the choice of the non perturbative QCD input parameters, such as the charm quark mass, m_c, or the QCD scale parameter Λ, compared with measurements of differential cross sections. The helicity analysis was performed in the so called target frame, where the quantization axis, z axis, is chosen along the opposite direction of the incoming proton in the J/ψ rest frame. The polar angle, $\theta^\star$, is defined as the angle between the μ^+ vector in the J/ψ rest frame and the quantization axis. To define the azimuthal vector, $\varphi^\star$, at least another axis is necessary. This axis was chosen, according to the prescriptions of [5], along the vector $\vec{p}_\gamma \times (-\vec{p}_p)$ in the J/ψ rest frame, y axis. The third axis, x axis, is chosen to complete a right–handed coordinate system in the J/ψ rest frame. With these definitions the decay angular distribution in the J/ψ rest frame can be parametrised as:

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega^\star dy} \propto 1 + \lambda(y)\cos^2\theta^\star + \mu(y)\sin 2\theta^\star \cos\varphi^\star + \frac{\nu(y)}{2}\sin^2\theta^\star \cos 2\varphi^\star$$

where the variable y can be either the p_T or the inelasticity z of the J/ψ. Integrating in $\theta^\star$ the parameterization can be written as:

$$\frac{1}{\sigma}\frac{d\sigma}{d\varphi^\star dy} \propto 1 + \frac{\lambda(y)}{3} + \frac{\nu(y)}{3}\cos 2\varphi^\star.$$

The HERA measurements of the parameter ν [1,6] as a function of the J/ψ inelasticity z are shown in the bottom left plot of Fig. 1. LO predictions obtained considering both CS and CO or CS only matrix elements are also shown, identified by the labels BKV(LO,CS+CO) and BKV(LO,CS), respectively. All data points are systematically below the CS only prediction, this trend being more pronounced for $z > 0.6$. The new data being recorded by both the H1 and ZEUS experiments after the HERA luminosity upgrade will be crucial to improve the experimental accuracy of this measurement.

References

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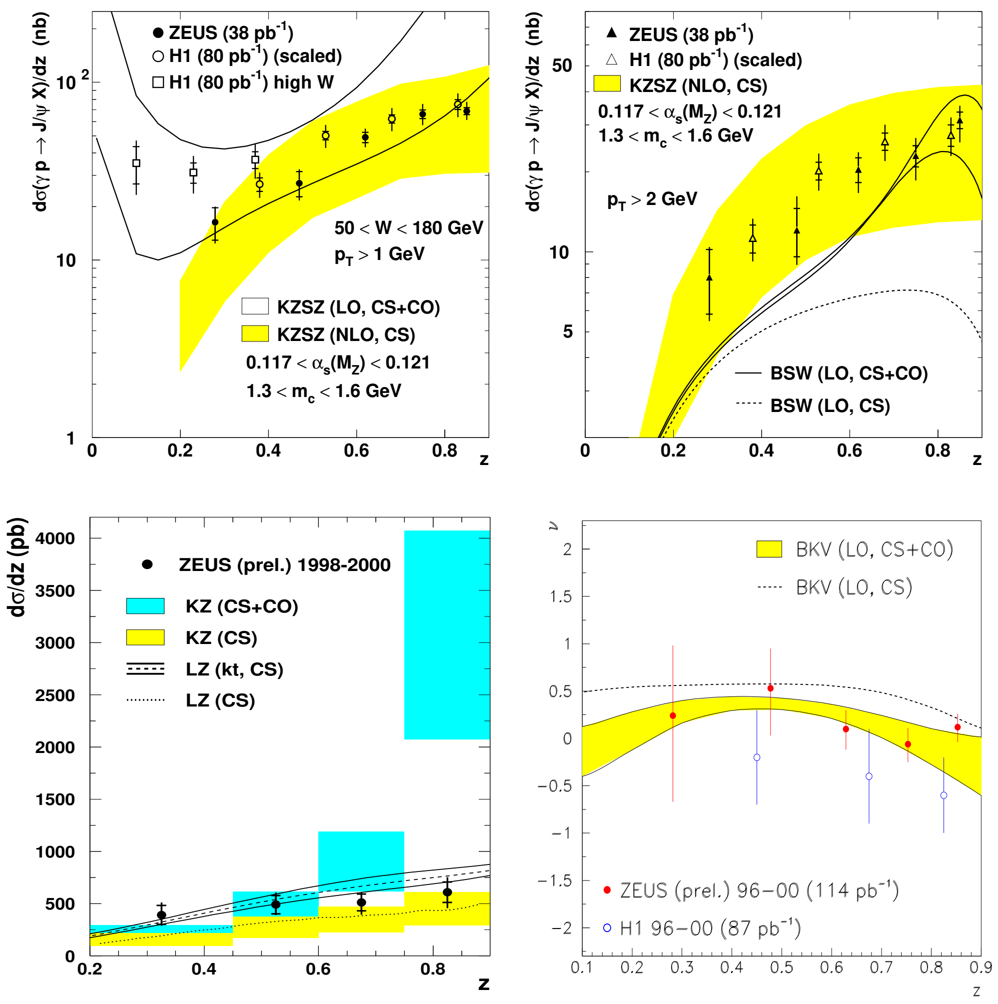

Figure 1. The top left and right plots show the HERA inelasticity differential cross section, measured in the photoproduction regime, for J/ψ $p_T > 1$ and for J/ψ $p_T > 2$ GeV, respectively. The data are compared to the theoretical predictions described in the text. The inelasticity differential cross section measured by the ZEUS experiment for $Q^2 > 2$ GeV^2 is shown in the bottom left plot. The data are compared to the theoretical predictions described in the text. The bottom right plot compares the HERA data on the helicity parameter ν as a function of the J/ψ inelasticity z with theoretical predictions with and without color octet matrix elements. More details can be found in the text.

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