PROCEEDINGS OF SCIENCE

Inelastic J/ψ differential cross sections with ZEUS at HERA

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A measurement of the inelastic J/ψ transverse momentum squared differential cross section in the photoproduction regime is presented. The measurement is performed with the data collected by the ZEUS experiment at the HERA collider. The differential cross section is measured in five different inelasticity ranges. Theoretical predictions within the non-relativistic QCD framework, including NLO colour-singlet and colour-octet contributions, and the k_T-factorization approach are compared to the data.

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1. Experimental overview

The inelastic J/ψ transverse momentum squared, p_t^2, differential cross section in electron proton collisions has been studied for low virtuality of the exchanged photon i.e. in the photoproduction regime. The data collected by the ZEUS experiment at the HERA collider, corresponding to an integrated luminosity of 468 pb^{-1}, have been used.

The online and offline selections, as well as the reconstruction of the kinematic variables, closely follow a previous analysis [1]. The mesons have been identified in the $\mu^+ \mu^-$ decay mode. The inelasticity, z, is defined as the fraction of the virtual photon energy carried by the meson in the proton rest frame. It has been restricted to the range from 0.1 to 0.9 thus excluding the diffractive process for which z ~ 1. The photon proton center-of-mass energy, W, range has been set to 60 < W < 240 GeV.

The diffractive background remaining after the z < 0.9 cut has been subtracted from the measured differential cross section using a fit to the observed z distribution in the extended range 0.1 < z < 1. The HERWIG and EPSOFT MC simulation have been used as templates for the signal and diffractive background contributions, respectively.

The presented cross section include a contribution from beauty hadron decays, less than 2 % on average, and a contribution from inelastic photoproduction of ψ(2S) mesons with subsequent cascade decay to J/ψ. This feed-down contributes about 15 % to the measured cross section. The estimate is obtained from the ψ(2S) to J/ψ cross section ratio measured in [1] and from the ψ(2S) → J/ψ X branching ratio. However, since an inclusive measurement of the reaction ψ(2S) → J/ψ X is not possible, a model independent subtraction of the ψ(2S) feed-down contribution is out of reach.

The transverse momentum squared differential cross section, measured in five different inelasticity bins, is shown in Fig. 1 and 2. The data are shown as points. The inner (outer) error bars represent the statistical (total) uncertainties.

2. Overview of available theoretical predictions

In the HERA photoproduction regime, the production of inelastic J/ψ mesons arises mostly from direct and resolved photon interactions. In leading-order (LO) Quantum Chromodynamics (QCD), the two processes can be distinguished: in direct photon processes the photon enters directly into the hard interaction, in resolved photon processes the photon acts as a source of partons, one of which participates in the hard interaction. The inelastic process in the photoproduction regime is dominated by photon gluon fusion. In this direct photon process the photon emitted from the incoming electron interacts with a gluon from the proton to produce a pair of charm anticharm quarks which then turn into the J/ψ mesons.

When the pair emerges from the hard process with the quantum numbers of the mesons, the reaction is described in the framework of perturbative Quantum Chromodynamics (pQCD) by models such as the Color Singlet (CS) model.

In the Color Octet (CO) model, the pair emerges from the hard process with quantum numbers different from those of the meson and emits one or more soft gluons before turning into the physical meson state. The non-relativistic QCD framework (NRQCD) allows the evaluation of J/ψ cross sections including direct and resolved photon processes with CS and CO contributions. Recently, the full computation was performed at the NLO level [2,3].

J/ψ cross sections have also been evaluated in the k_T-factorization approach [4,5]. In this model, based on non-collinear parton dynamics governed by the CCFM evolution equations, effects of non-zero gluon transverse momentum are taken into account. Cross sections are then calculated as the convolution of unintegrated, transverse-momentum dependent, gluon densities and LO off-shell matrix elements. Direct and resolved photon processes are included. The matrix elements are computed in the CS model.

3. Comparison with theoretical predictions

In Fig. 1 the prediction from [2,3], performed in the NRQCD framework, including direct and resolved photon processes, is compared to the measured differential cross section. The NRQCD hard processes take into account both CS and CO terms at NLO. The square of the renormalization and factorization scales used is $4\ m_c^2 + p_t^2$. The charm quark mass, m_c, is set to 1.5 GeV and the strong coupling constant, $\alpha_s(M_Z)$, to 0.118. The NRQCD scale, connected to the color-octet terms, is set to m_c. The central value is given by the continuous line. The spread, shown by the boxes, estimates the uncertainties due to the renormalization, factorization and non-relativistic QCD scales. The CS contribution alone predicts cross sections significantly below the data and fails to describe the shape in all z regions shown here. Including CO terms give a dramatic improvement and leads to a rough agreement with data. In general the calculation reproduces the steep drop of the measured cross section, however, in the intermediate z range, $0.3 < z < 0.75$, the prediction rises less steeply than the data towards the smallest values of p_T^2.

In Fig. 2 a prediction [4,5] performed in the k_T-factorization approach is compared to the ZEUS measurements. The matrix elements are computed in the CS model using $m_c = 1.5$ GeV and $\alpha_s(MZ) = 0.1232$. In the calculation, the renormalization and factorization scales squared are set to $m_{J/\psi}^2 + p_t^2$ and È + Q_t^2, respectively, where È is the four-momentum squared of the hard process and Q_t is the transverse momentum of the initial off-shell gluon or gluon pair, in the case of the resolved photon component. The unintegrated CCFM parton density was selected. The central value is given by the continuous line, the band is obtained by varying the renormalization and factorization scales by ½ and 2 with respect to the central values given above. Using different sets of parton densities leads to changes in the prediction that are small with respect to the effects of scale variations already shown in Fig. 2. Therefore this source of theoretical uncertainties was neglected. The k_T-factorization prediction, with the values of m_c, factorization and renormalization scales given above, provides a better description of the data than the NRQCD model.

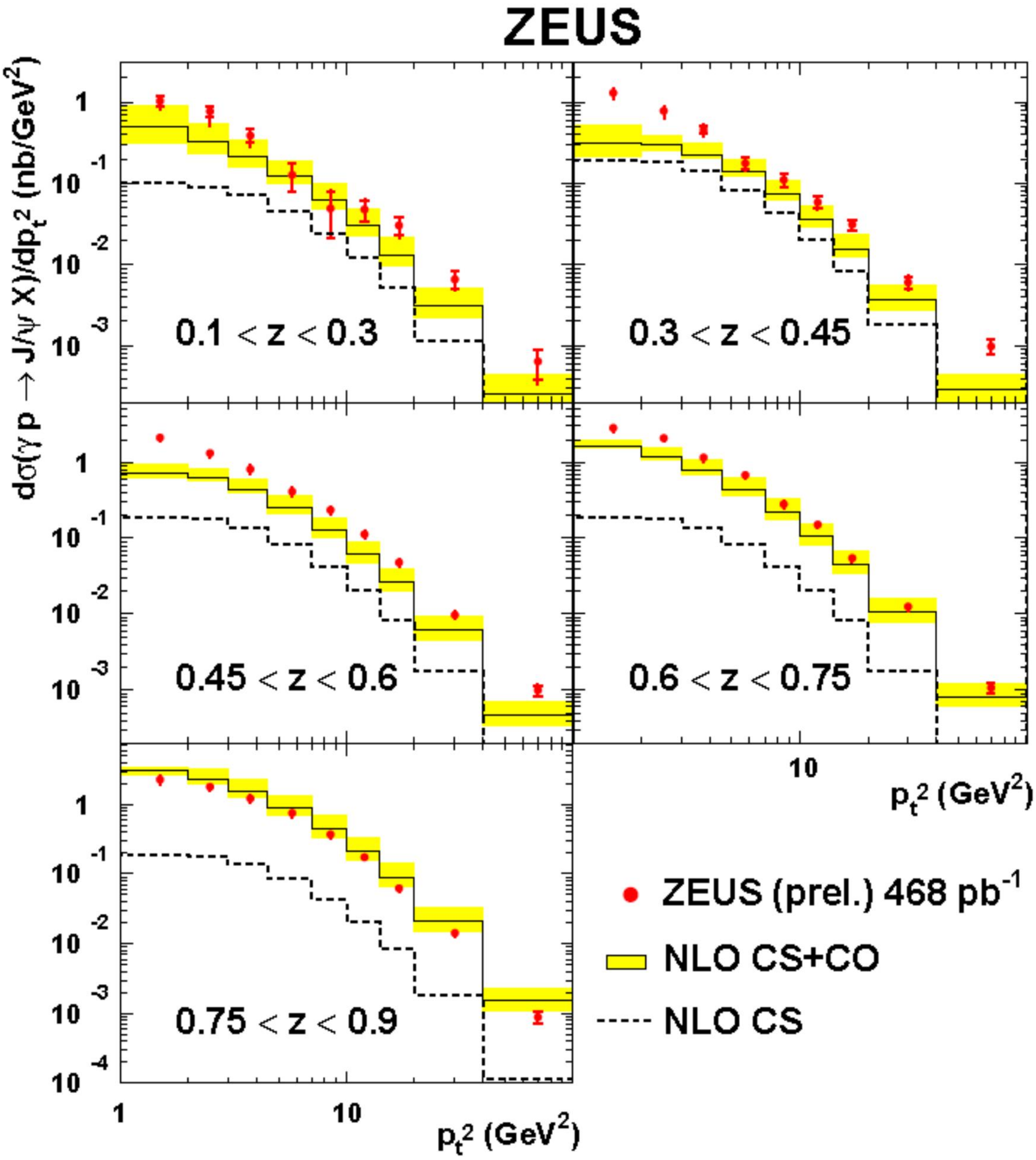

Figure 1: transverse momentum squared differential cross section measured in 5 different z ranges. The prediction of a NLO NRQCD calculation, including CS+CO or CS terms alone, is compared to the data. See text for further details.

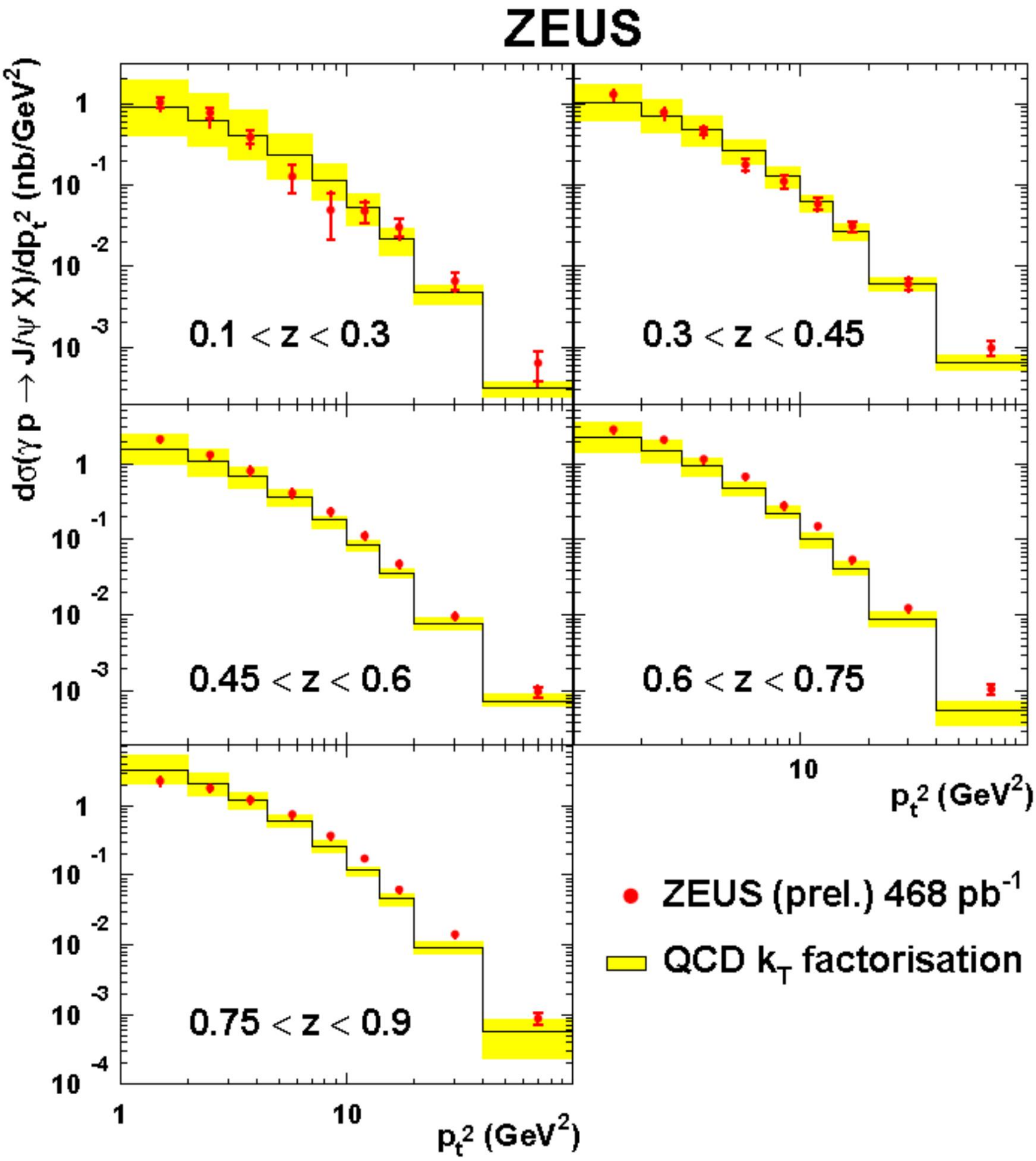

Figure 2: transverse momentum squared differential cross section measured in 5 different z ranges. The prediction of a LO QCD calculation performed in the k_T-factorization framework is compared to the data.

4. Conclusions

The inelastic J/ψ photoproduction transverse momentum squared differential cross section has been presented in five different inelasticity ranges. A LO k_T calculation [4,5] using CS terms alone gives, within large normalization uncertainties, a good description of the measurements.

However, for a better comparison with data, a reduction of the theoretical uncertainties is very important.

A recent NLO calculation [2,3], using CS and CO terms in the collinear approximation, gives a rough description of the presented measurements. The same calculation with only CS terms is in strong disagreement with data. This leads to the conclusion that CO terms are an essential ingredient for this particular model.

So, even if inelastic J/ψ production is being studied both experimentally and theoretically since a few decades [6], a satisfactory picture of this process is yet to come.

References

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