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Measurement of inelastic J/ψ and $\psi(2S)$ photoproduction at HERA

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The ZEUS experiment performed an update of the inelastic charmonium measurements at HERA using the full available luminosity. The most accurate $\psi(2S)$ to J/ψ cross section ratios and the differential cross sections in p_T^2 and z, the inelasticity, will be briefly reviewed. Finally the new measurement of the momentum flow along and against the J/ψ direction will be presented.

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1. Introduction

The ZEUS experiment performed an update of the inelastic charmonium measurements at HERA using the full available luminosity [1]. The updated ψ' to J/ψ cross section ratio, measured using the rates of $\psi' \to \mu^+\mu^-$ and $J/\psi \to \mu^+\mu^-$, will be presented first. Then the differential J/ψ cross sections in p_T^2 and z, the inelasticity, will be briefly reviewed. Finally the new measurement of the momentum flow along and against the J/ψ direction will be discussed.

2. $\psi(2S)$ to J/ψ cross section ratios

The ψ' to J/ψ cross section ratio was determined in the region $60 < W < 190$ GeV and $0.55 < z < 0.9$. Here and in the following W is the photon proton center of mass energy and z is the inelasticity. The ψ' to J/ψ cross section ratio was computed in bins of W, z and p_T, as shown in Fig. 1. Since NLO predictions are not available for ψ', only the LO CS model expectations can be compared to the data. In the CS model, the underlying production mechanism is the same for J/ψ and ψ' hence all cross section ratios should be largely independent of the kinematic variables. Since the NLO corrections, though being large, should be similar for J/ψ and ψ', the ratio at NLO is not expected to differ significantly from that at LO. The results, Fig. 1, are dominated by the statistical uncertainties while most of the systematic uncertainties cancel in the ratio. The LO CS predictions agree reasonably well with the data.

3. Differential cross sections measurements

The J/ψ differential cross sections presented here include the inelastic ψ' feed–down via the decay $\psi' \to J/\psi\ (\to \mu^+\mu^-)\ X$ and the contribution from b hadron decays. The ψ' feed–down contributes about 15% and the b hadron decays 1.6%. The differential cross sections $d\sigma/dp_T^2$ were measured in the range $1 < p_T^2 < 100$ GeV^2, $60 < W < 240$ GeV, for different z intervals. The results are shown in Figs. 2. The predictions of a NRQCD calculation [2, 3] and those based on the k_T–factorization approach [5] are compared to the data.[1] The NRQCD prediction retaining only the color singlet, CS, terms fails to describe the data in all z regions shown here. Including also color octet, CO, terms give a dramatic improvement and leads to a rough agreement with the data. The k_T–factorisation prediction, using the charm quark mass and the strong coupling constant values presented in [5], provides a better description of the data.

The differential cross sections $d\sigma/dz$ were measured in the range $0.1 < z < 0.9$ for different p_T ranges. The results are shown in Figs. 3 and compared to the same theoretical predictions mentioned above. The NRQCD predictions rise too steeply with z compared to the data, for all the p_T ranges. Here too the k_T–factorisation model is providing a better description of the data. Note however that the k_T–factorisation prediction suffers from large theoretical uncertainties, in particular at low p_T.

[1]Both the NRQCD and the k_T–factorisation calculations do not include ψ' feed–down and b hadron decays, however these expected contributions are small compared to the uncertainties of the calculations.

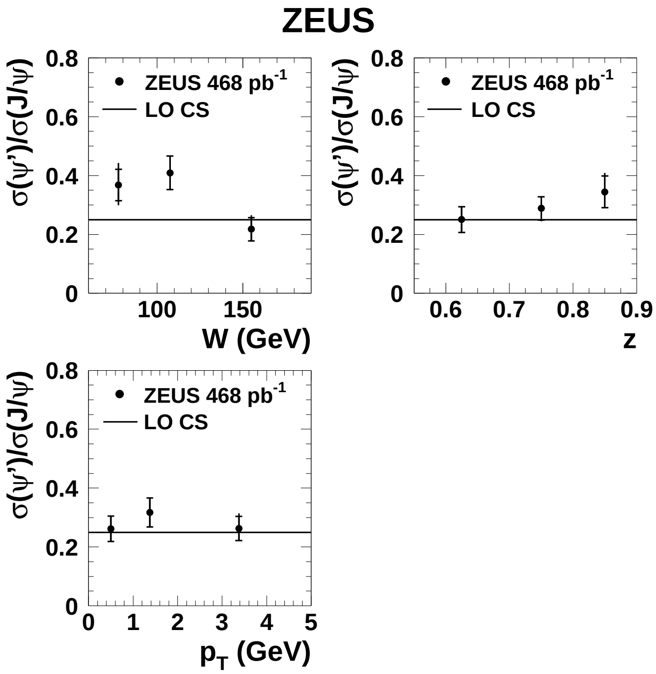

Figure 1: ψ' to J/ψ photoproduction cross section ratio measured in the kinematic region $0.55 < z < 0.9$ and $60 < W < 190$ GeV as a function of W, upper left, the inelasticity z, upper right, and p_T, lower left. The data are shown as points. The inner error bars are the statistical uncertainties, while the outer error bars show the statistical and systematic uncertainties added in quadrature. The leading-order colour-singlet model expectation (horizontal lines) is also shown.

4. Momentum flow along and against the J/ψ direction

The different colour flow in CS and CO hard subprocesses is expected to translate into different properties of the hadronic final state. In the photoproduction regime, the transverse momentum of the incoming photon is negligible. Thus in the CS model at LO the J/ψ and the final state gluon are expected to be back to back. Hence, in this model, the momentum flow along the J/ψ direction, $P_{\rm along}$, is expected to be small. The momentum flow against the J/ψ direction, $P_{\rm against}$, should instead be driven by the hadronisation of the gluon. In the CO framework no substantial difference is expected for $P_{\rm against}$, compared to the CS framework. Instead, a contribution due to the soft gluons emitted by the $c\bar{c}$ pair forming the physical J/ψ state should be present. Hence, $P_{\rm against}$ is again sensitive to gluon fragmentation while $P_{\rm along}$ can shed light on the CO dynamics. The momentum flow analysis was performed for different p_T ranges. All track quantities described in the following were measured in the laboratory frame at the reconstruction level. Only primary vertex tracks with $p_T > 150$ MeV and $|\eta| < 1.75$ were selected. The J/ψ decay muon tracks were discarded. For each track whose component of momentum along the J/ψ direction in the laboratory frame was positive, the component was included in $P_{\rm along}$. If it was negative, it was included, in absolute value, in $P_{\rm against}$. The data were restricted to $z > 0.3$ where the signal to background ratio is highest. The W and p_T ranges were $60 < W < 240$ GeV and $1 < p_T < 10$ GeV, respectively. The $P_{\rm against}$ ($P_{\rm along}$)

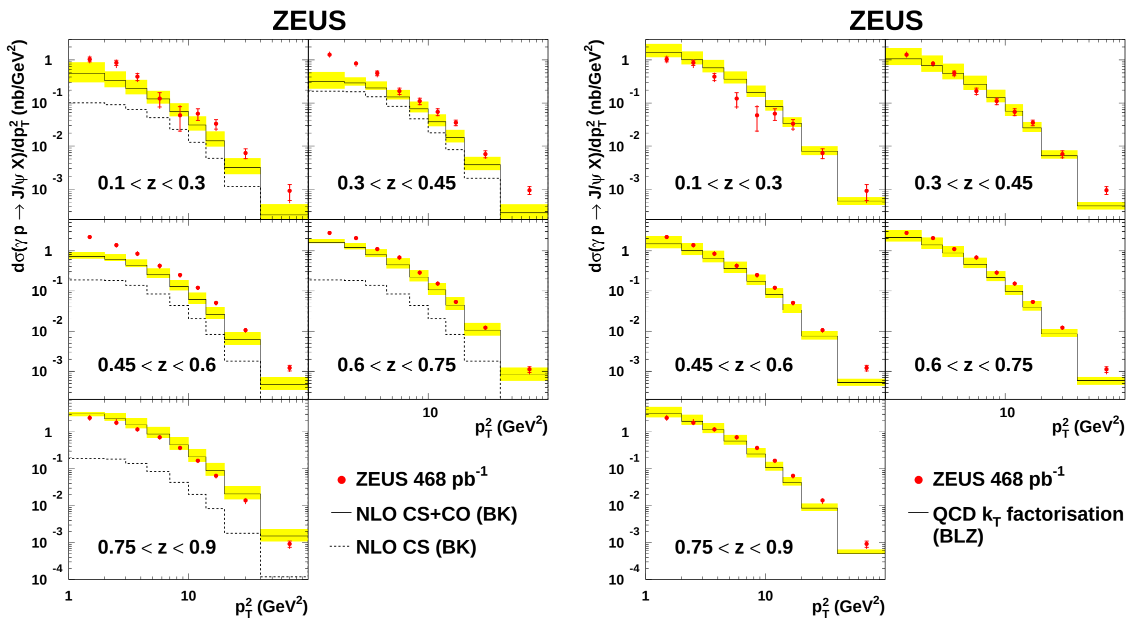

Figure 2: Differential cross sections $d\sigma/dp_T^2$ measured in 5 different z ranges. The measurement is performed in the kinematic region $60 < W < 240$ GeV and $p_T > 1$ GeV. The same ZEUS data, shown as points, as displayed on the left and right pannels. The inner (outer) error bars represent the statistical (total) uncertainties. The left pannel solid lines show the NLO CS+CO (BK) prediction [2, 3] obtained in the non-relativistic QCD framework. The colour-singlet model contribution is presented separately as the dashed lines. The right pannel solid lines show the k_T–factorisation (BLZ) prediction [4, 5]. In both pannels the theoretical uncertainties are indicated by the band.

distribution, normalized to one, are shown in Fig. 4. The prediction obtained from the HERWIG MC simulation (including detector simulation) is also shown. The P_{against} distribution of the MC simulation shows a softer drop from the first to the second momentum bin than that of the data. This situation is reversed for the higher momenta values where HERWIG predicts a steeper decrease than that observed in the data. This behavior is seen for all p_T regions. For the P_{along} distribution a better agreement is found between the HERWIG MC prediction and the data.

5. Conclusions

A summary of the recent inelastic J/ψ and ψ' photoproduction measurements at HERA was presented. The ψ' to J/ψ cross section ratio was measured as a function of several kinematical observables. The constant value of 0.25 predicted by the LO CS model is in reasonable agreement with the data. Inelastic J/ψ photoproduction cross sections were measured. A LO k_T calculation using CS terms alone gives, within large normalisation uncertainties, a good description of the differential cross sections. However, for a better comparison with the data, a reduction of the theoretical uncertainties is very important. A recent NLO calculation, using CS and CO terms in the collinear approximation, gives a rough description of the double differential cross sections. The same calculation with only CS terms is in strong disagreement with the data. This leads to the

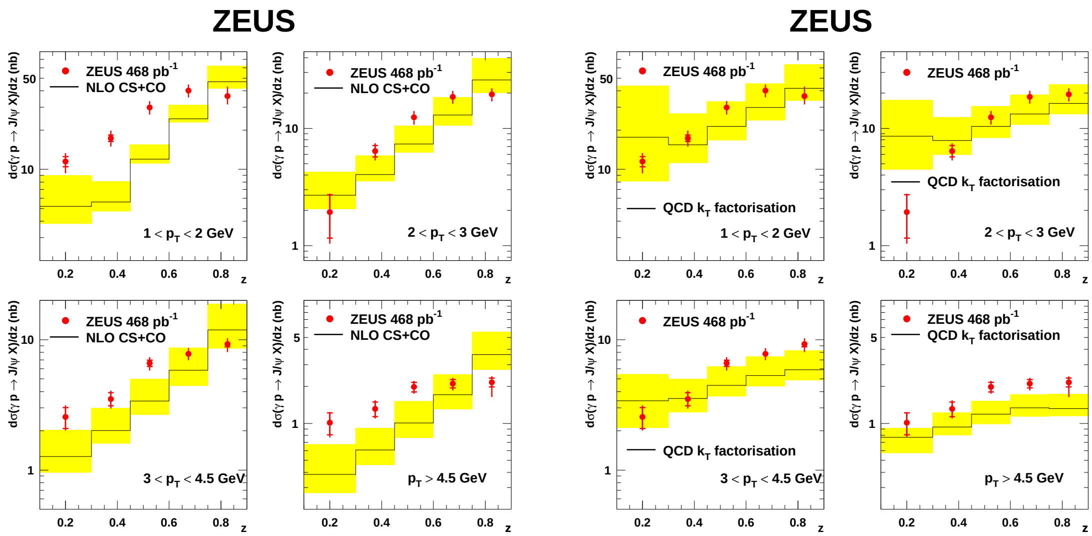

Figure 3: Differential J/ψ cross sections $d\sigma/dz$ measured in 4 different p_T ranges. The measurement is performed in the kinematic region $60 < W < 240$ GeV and $0.1 < z < 0.9$. The same ZEUS data, shown as points, as displayed on the left and right pannels. The inner (outer) error bars represent the statistical (total) uncertainties. The left pannel solid lines show the NLO CS+CO (BK) prediction [2, 3] obtained in the non-relativistic QCD framework. The right pannel solid lines show the k_T–factorisation (BLZ) prediction [4, 5]. In both pannels the theoretical uncertainties are indicated by the band.

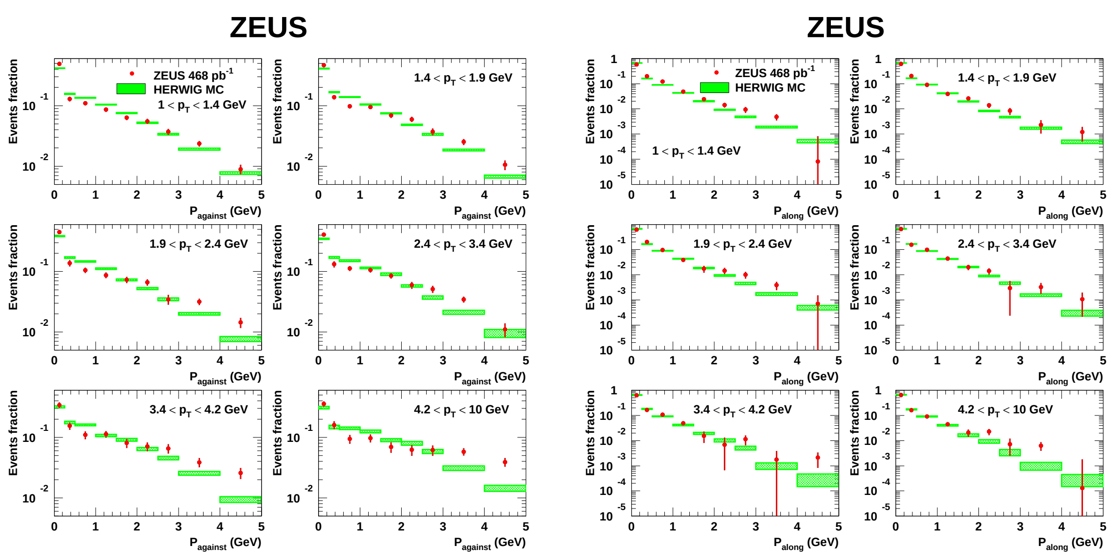

Figure 4: Momentum flow against, left pannel, and along, right pannel, the J/ψ direction of flight in the laboratory frame for different p_T ranges. The distributions are normalized to unity and are not corrected for detector acceptance. The measurement is performed in the kinematic region $60 < W < 240$ GeV and $0.3 < z < 0.9$. The data are shown as points with error bars indicating their uncertainties. The predictions obtained from the HERWIG MC are also shown as rectangular shaded boxes. The height of these boxes represents the uncertainties of the prediction.

conclusion that CO terms are an essential ingredient for this particular model. Predictions of the HERWIG MC, which includes only CS processes, were compared to the measured momentum flow along and against the J/ψ direction. HERWIG reproduces the fall off of the momentum distribution against the J/ψ direction as the momentum increases but fails to describe the exact shape of this distribution. A better description is obtained along the J/ψ direction.

References

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