PROCEEDINGS OF SCIENCE

Inelastic J/ψ helicity distributions

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The J/ψ decay angular distributions have been measured in inelastic photoproduction in ep collisions with the ZEUS detector at HERA, using an integrated luminosity of 468 pb^{-1}. The range in photon-proton centre-of-mass energy, W, was $50 < W < 180$ GeV. The J/ψ mesons were identified through their decay into muon pairs. The polar and azimuthal angles of the μ^+ were measured in the J/ψ rest frame and compared to theoretical predictions at leading and next-to-leading order in QCD.

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1. Introduction

In the HERA photoproduction regime, where the virtuality of the exchanged photon is small, the production of inelastic J/ψ mesons is dominated by boson-gluon fusion: a photon emitted from the incoming lepton interacts with a gluon coming from the proton to produce a $c\bar{c}$ pair which subsequently forms a J/ψ meson. Production of J/ψ through boson-gluon fusion can be calculated using perturbative Quantum Chromodynamics (pQCD) in the colour-singlet (CS), in the non-relativistic QCD (NRQCD) and in the k_T-factorisation frameworks.

In the CS approach, only the colourless $c\bar{c}$ pair produced in the hard subprocess can lead to a physical J/ψ state. In the NRQCD approach, a $c\bar{c}$ pair emerging from the hard process in a colour-octet (CO) state can also evolve into a J/ψ state with a probability proportional to universal long-distance matrix elements (LDME) that are obtained from experiment. In the k_T-factorisation approach, the effects of non-zero transverse momentum of the incoming parton are taken into account. Cross sections are then calculated in the CS approach as a convolution of unintegrated (transverse-momentum dependent) parton densities and leading-order (LO) off-shell matrix elements.

The polar and azimuthal distributions of the J/ψ decay leptons in the J/ψ rest frame, the helicity distributions, may be used to distinguish between CS and CO models [1]. Helicity distribution measurements have already been performed by the ZEUS [2] and H1 [3, 4] collaborations. The data sample of this study [5] includes the data used in the previously published ZEUS analysis [2] and corresponds to an increase in statistics of a factor of 12.

2. Data analysis

J/ψ mesons were identified using the decay mode $J/\psi \to \mu^+\mu^-$. The online and offline selections as well as the reconstruction of the kinematic variables closely follow a previous analysis [2]. The transverse momentum, p_T, of the J/ψ candidate was required to be larger than 1 GeV. The photon-proton centre-of-mass energy W was restricted to the range $50 < W < 180$ GeV. In addition, events were required to have an energy deposit larger than 1 GeV in a cone of 35° around the forward direction (excluding possible calorimeter deposits due to the decay muons). According to Monte Carlo (MC) simulations, these requirements completely reject exclusively produced J/ψ mesons ($ep \to epJ/\psi$) as well as proton-diffractive events ($ep \to eYJ/\psi$) in which the mass of the proton dissociative state, M_Y, is below 4.4 GeV. To further reduce diffractive background, events were also required to have at least one additional track with a transverse momentum larger than 0.125 GeV and pseudorapidity $|\eta| < 1.75$.

The following other sources of J/ψ mesons, which were classified as background in the present analysis, were estimated either from MC models or previous measurements:

- diffractive production of J/ψ mesons with proton dissociation: the overall contribution of this background is 6%; it is largest in the lowest p_T bin ($1 \leq p_T \leq 1.4$ GeV), where it is 7.5%, and in the highest z bin ($0.9 \leq z \leq 1$), where it is 66%;

- J/ψ mesons originating from B-meson decays: 1.6% of the observed J/ψ events were from B-meson decays; the fraction is largest in the highest p_T bin ($4.2 \leq p_T \leq 10$ GeV), where it is equal to 6.3%, and in the lowest z bin ($0.1 \leq z \leq 0.4$), where it is 8.4%

- J/ψ from $\psi^{'}$ decays: this contribution is expected to be around 15%, as obtained using the direct measurement of the $\psi^{'}$ to J/ψ cross section ratio [2] and the branching ratio of the ψ' to J/ψ.

Although the relative rate of each process could be estimated, the helicity distributions of these J/ψ sources are poorly known, so these contributions were not subtracted.

The helicity analysis was performed in the so-called "target frame" [1]. The polar and azimuthal angles of the μ^+ in this frame are denoted $\theta^\star$ and $\phi^\star$. The differential cross sections in $\theta^\star$ and $\phi^\star$ can be parametrised as [1]:

$$\frac{d\sigma}{d\cos\theta^\star} \propto 1+\lambda\cos^2\theta^\star, \tag{2.1}$$

$$\frac{d\sigma}{d\phi^\star} \propto 1+\frac{\lambda}{3}+\frac{\nu}{3}\cos 2\phi^\star, \tag{2.2}$$

where λ and ν, the polar and azimuthal angular parameters, are functions of p_T and z. The λ and ν parameters were determined in bins of z and p_T, each time integrating over the other variable. As a function of p_T, the integration range for z was set to $0.4 < z < 1$, thereby avoiding the region $0.1 < z < 0.4$ where the ratio of signal to combinatorial background is rather poor. The integration range in p_T started at p_T = 1 GeV.

The HERWIG MC generator-level distributions $dN/d\cos\theta^\star$ ($dN/d\phi^\star$) were re-weighted according to Eq. 2.1 (2.2) within a search grid of λ (ν) values. For each re-weighted distribution, the value of χ^2 was calculated from a comparison to the data. The λ (ν) value providing the minimum χ^2, $\chi^2_{\rm min}$, was taken as the central value. The parameter values with $\chi^2 = \chi^2_{\rm min}+1$ were used to calculate the statistical uncertainties. Equation 2.1 was first used to extract λ, and then λ was inserted into Eq. 2.2 to extract ν.

3. Results

The values of the parameter λ are shown as a function of p_T and z in Figs. 1a) and b), respectively; the values of the parameter ν are displayed in Figs. 2a) and b).

The data are compared to various theoretical predictions for photoproduction, at $Q^2 = 0$. These predictions do not consider the polarisation due to J/ψ coming from $\psi^{'}$ decays, B-meson decays and from diffractive processes. The curves identified by the label LO CS show the LO prediction in the CS framework including both direct and resolved[1] processes. The two lines identified by the label LO + k_T (JB) and LO + k_T (dGRV), represent the predictions of a k_T-factorisation model using two different unintegrated gluon distributions and including only direct processes. The band identified by the label NLO CS represents the predictions of a NLO calculation including only direct processes. The width of the band gives the uncertainties of the calculation due to variations of the renormalisation and factorisation scales. It stops at $z = 0.9$ because no reliable predictions can be obtained near $z = 1$ for this fixed-order calculation. The band identified by the label LO CS+CO shows a LO prediction including direct and resolved processes in the NRQCD approach

[1]In these resolved processes, the incoming photon does not couple to the c quark directly, but via its hadronic component. They are expected to contribute mainly to the region of $z < 0.4$.

and hence involving CS plus CO states. The width of the band results from the uncertainties in the values of the CO matrix elements. In Figs. 1a) and 2a), with z integrated up to $z = 1$, the LO CS+CO cross section is CO dominated.

The NLO CS calculation for $p_T > 1$ GeV suffers from large scale uncertainties. In order to avoid this problem, measurements and calculations were repeated increasing the p_T cut first to 2 GeV and then to 3 GeV. In Figs. 3a) and b) the λ and ν parameters, respectively, are shown as a function of z for $p_T > 2$ GeV, while in Figs. 3c) and d) the same parameters are displayed for $p_T > 3$ GeV. The NLO CS calculation, also shown in these figures, has now smaller uncertainties, but the agreement with the data is only satisfactory for the ν parameter. Sizeable discrepancies remain for the λ parameter both for $p_T > 2$ GeV and $p_T > 3$ GeV.

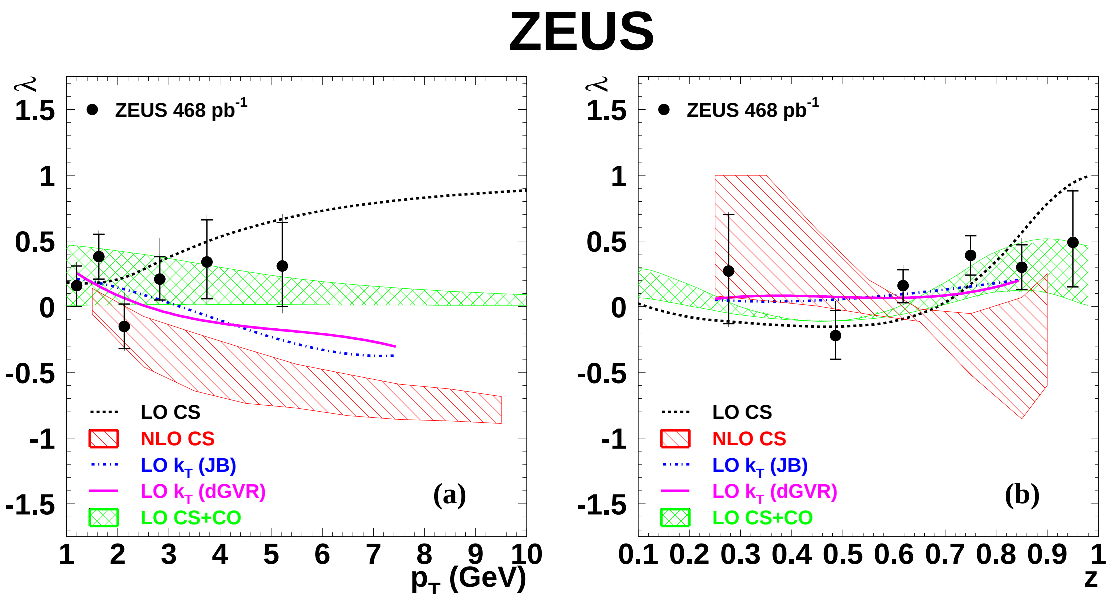

Figure 1: The helicity parameter λ, measured in the target frame, as a function of (a) p_T, and (b) z. The measurement is performed in the kinematic range $50 < W < 180$ GeV, $0.1 < z < 1$ and $p_T > 1$ GeV. The measurement as a function of p_T is restricted to the kinematic range $0.4 < z < 1$. The inner (outer) error bars correspond to the statistical (total) uncertainty. The theoretical curves are described in the text.

4. Conclusions

The J/ψ helicity distributions in the inelastic photoproduction regime have been measured using a luminosity of 468 pb^{-1}. The J/ψ helicity parameters λ and ν were extracted in the target frame as a function of the transverse momentum and of the inelasticity of the J/ψ. The results were compared to LO QCD predictions in the colour-singlet, colour-singlet plus colour-octet and k_T factorisation frameworks. A recent NLO QCD prediction in the colour-singlet framework was also considered. Even though the experimental and theoretical uncertainties are large, none of the predictions can describe all aspects of the data.

References

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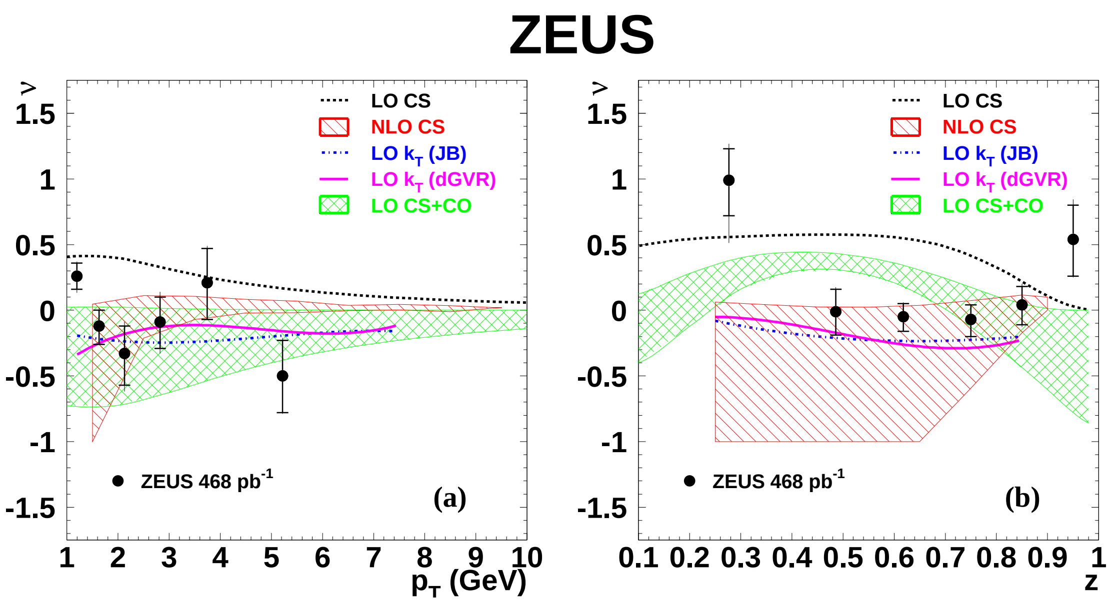

Figure 2: The helicity parameter ν, measured in the target frame, as a function of (a) p_T, and (b) z. The measurement is performed in the kinematic range $50 < W < 180$ GeV, $0.1 < z < 1$ and $p_T > 1$ GeV. The measurement as a function of p_T is restricted to the kinematic range $0.4 < z < 1$. The inner (outer) error bars correspond to the statistical (total) uncertainty. The theoretical curves are described in the text.

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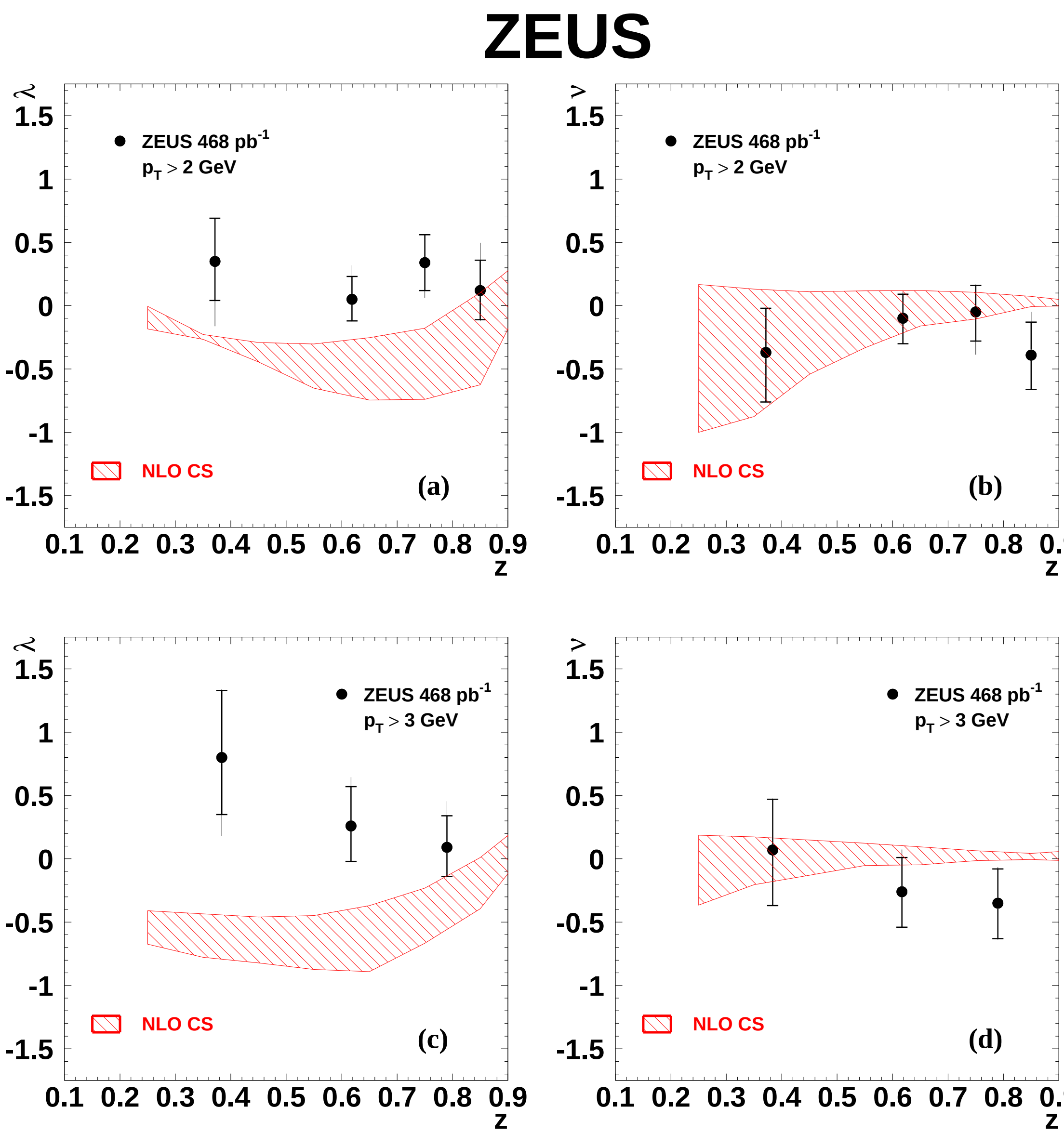

Figure 3: Distributions of the helicity parameters (a), (c) λ and (b), (d) ν as a function of z, measured in the target frame, for $50 < W < 180$ GeV, $0.1 < z < 0.9$ and (a), (b) $p_T > 2$ GeV and (c), (d) $p_T > 3$ GeV. The inner (outer) error bars correspond to the statistical (total) uncertainty. The theoretical bands are described in the text.