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Proton Dissociative J/ψ Production at High $|t|$ at HERA

H1 Collaboration

Abstract

A measurement of the diffractive production of J/ψ mesons at large four-momentum transfers squared (t) is presented in photoproduction at HERA. The J/ψ meson is identified via its decay into two unlike-sign muons. The cross section $\sigma(\gamma p \to J/\psi X)$ is measured as a function of $|t|$ and as a function of the photon-proton centre-of-mass energy $W_{\gamma p}$ in two $|t|$ intervals. The results are compared with perturbative QCD calculations.

1 Introduction

The large $|t|$ region ($|t| \geq 1.0~\mathrm{GeV}^2$), where t is the four-momentum transfer squared at the proton vertex, represents the region relevant to the so-called hard BFKL pomeron. This is described by an effective ladder of Reggeized gluons within the framework of perturbative QCD. Predictions for the diffractive production of the J/ψ meson, through the exchange of the hard BFKL pomeron, have been completed in leading order, where the mass of the J/ψ and the large $|t|$ values both provide relevant scales, and demonstrate that the total cross section for this process, although small, is not expected to be restrictively small at the energies accessible to the HERA collider [1]. The differential cross section $d\sigma/d|t|$ is expected to have a more gradual $|t|$-dependence in the high $|t|$ region [2] than at low $|t|$ where the differential cross section can be described by the exponential parameterisation of Regge theory. The large $|t|$ values result predominantly in the dissociation of the proton giving rise to a proton remnant final state X.

The pQCD predictions are based upon a 'low-energy' approximation to the full perturbative BFKL expansion. The incoming photon at HERA is assumed to fluctuate into a quark-antiquark pair some long time before interacting with the proton. The wavefunction of the outgoing meson is not known but is assumed to be a delta function which partitions the momenta of the incoming quarks in the photon equally. This choice of wavefunction to describe the produced meson is expected to be particularly appropriate for heavier mesons. The predictions depend upon the 'scaling variable' $\tau = -t/(M_V + Q^2)$, where Q^2 is the photon virtuality and M_V is the mass of the produced meson. The only parameter in the leading-order model is $\overline{\alpha}_s$, which is related to the QCD coupling constant α_s according to $\bar{\alpha}_s = (N\alpha_s)/\pi$ for a colour group SU(N) and is treated as a free parameter. The event generator HITVM is used to generate proton dissociative, diffractive J/ψ events at large $|t| > 1.0~\mathrm{GeV}^2$ according to the pQCD calculation [3].

The proton-dissociative production of the J/ψ meson, $\gamma p \rightarrow J/\psi X$, is studied here in the kinematic region of photoproduction. In photoproduction at HERA the incoming lepton scatters through a small angle emitting an 'almost-real' photon. The total cross section is presented as a function of the centre-of-mass energy of the initial photon-proton system ($W_{\gamma p}$) in two separate regions of $|t|$. The differential cross section $d\sigma/d|t|$ is presented as a function of $|t|$ for the $|t|$-range $1.0 < |t| < 21.0~\mathrm{GeV}^2$.

2 Event Selection.

Proton dissociative, diffractive J/ψ events are selected from data collected by the H1 detector at HERA during 1999. During the first part of 1999 HERA collided beams of 27.6 GeV electrons with 920 GeV protons. The electron beam was replaced by a positron beam of the same energy during the year.

The analysis is based on a total integrated luminosity of $19.1~\mathrm{pb}^{-1}$. The measurement is performed in the kinematic region of photoproduction in the photon-proton centre-of-mass energy range $50 < W_{\gamma p} < 160~\mathrm{GeV}$. The J/ψ mesons are identified via their decays to two unlike-sign muons.

To restrict the analysis to small photon virtualities, events are rejected in which a scattered lepton with an energy deposit $E > 8.0$ GeV is detected in the main part of the detector. The kinematic acceptance is thereby restricted to $Q^2 < 1.0$ GeV^2.

The polar angle θ is measured with respect to the incoming proton, or forward, direction. Events in which only two tracks are reconstructed with transverse momenta greater than 0.8 GeV in the polar angular range $30° < \theta < 160°$ are selected. Both tracks originate from a vertex within $z = \pm 40$ cm of the nominal interaction point. Both tracks are identified as minimum ionizing particles in the calorimeter and/or by their hits in the instrumented iron yoke. Two different triggers which use a combination of tracking, muon and z-vertex requirements are used to collect the events. A detailed description of the H1 detector can be found in [4].

Proton dissociative events are selected by requiring either hits in the forward muon detector, activity in the proton remnant tagger or energy deposits in the forward part of the LAr calorimeter ($4° < \theta < 10°$). Proton dissociative events in which narrower final states are produced can be detected by this method if interactions of the final state particles with material in the forward region leads to secondary scattering in the forward detectors. The acceptance of these detectors restricts the proton remnant mass to ($M_X > 1.6$ GeV).

The proton remnant is restricted to the range $\theta \leq 20°$ by requiring an energy deposit $E \leq 1.0$ GeV in the main calorimeter in the region $20° < \theta < 30°$. This restricts the selection to proton remnant masses $M_X < 30$ GeV. The expected contribution (from Monte Carlo studies) of events produced with elasticities $z < 0.9$ is restricted to about 1% by this method. The inelastic contribution is thus suppressed. The momentum transfer squared $|t|$ at the proton vertex can then be reconstructed using the approximation $|t| = p_{t,J/\psi}^2$ (where $p_{t,J/\psi}$ is the transverse momentum of the J/ψ meson). The invariant mass distribution of the events selected in the regions $1.0 < |t| < 5.0$ GeV^2 and $|t| > 5.0$ GeV^2 are shown in figure 1.

3 Data Analysis

The event generator HITVM is used to generate proton dissociative, diffractive J/ψ events at large $|t| > 1.0$ GeV^2 according to the pQCD calculation with an input value $\overline{\alpha}_s = 0.2$ [3]. The generated events were passed through a full simulation of the H1 detector response. Good agreement between the data and the HITVM Monte Carlo simulation is obtained. In addition, the distributions of the HITVM Monte Carlo sample were compared in detail with the distributions of the event generator DIFFVM [5] in the region of overlap $1.0 < |t| < 4.0$ GeV^2. A good agreement of the simulated momentum and angular distributions of the decay muons and the detector acceptances and efficiencies for triggering, track reconstruction, selection and muon identification between HITVM and DIFFVM was found. The resulting average acceptance exhibits a flat dependence in $|t|$.

A correction factor of 4% is subtracted and an error of $\pm 4\%$ is attributed to the measured cross sections to allow for the maximum 8% of the selected sample which is expected to originate through the decay of the $\psi(2S)$, or ψ', meson. The maximum contribution is estimated using the published ratio $\sigma_{\psi'}/\sigma_{J/\psi} = 0.15 \pm 0.027_{stat} \pm 0.022_{sys}$, measured by the H1 collaboration in the same Q^2 region [6], and the expected branching ratio of $55 \pm 5\%$ for the decay of the ψ' into the J/ψ with the production of other particles. The published $|t|$-dependency of the ψ' cross section is compatible, within errors, to that of the J/ψ therefore a $|t|$-dependent correction is not made.

The contribution to the sample through events in which an additional initial state photon is emitted by the incoming lepton is found to be neglible. The contribution of events with an additional low p_t initial photon was investigated using the H1 luminosity system. The contribution (6%) can be almost completely attributed to Bethe-Heitler $ep \to ep\gamma$ events overlapping in the same bunch crossings. Potential migration effects of events in $|t|$ were also investigated using events generated with and without radiation using the Monte Carlo event generator DIFFVM and were found to be negligible.

Uncertainties in the detector acceptance and efficiency calculations contribute to systematic uncertainties in the cross-section measurements and are estimated based on dedicated studies and the results of earlier analyses of elastic J/ψ production in diffraction at smaller values of $|t|$ [7, 8]. The most significant systematic uncertainties arise from the trigger efficiency (6%), lepton identification efficiency (5%) and track reconstruction efficiency (4%) as well as from the determination of the geometrical acceptance. To determine the systematic uncertainty in the geometric acceptance the decay angular distribution for J/ψ decaying directly into two muons was varied from the prediction of s-channel helicity conservation to a flat dependence and the observed deviation added to the systematic uncertainty. The attributed uncertainty in the forward detector response for the classification of proton-dissociative events is of decreasing magnitude and falls to 2% with increasing $|t|$. All errors are added in quadrature.

4 The $W_{\gamma p}$ Dependence of the Total Cross Section.

The differential cross section $\sigma(\gamma p \to J/\psi X)$ is shown as a function of $W_{\gamma p}$ for $1.0 < |t| < 5.0 \text{ GeV}^2$ and $|t| > 5.0 \text{ GeV}^2$ in photoproduction in figure 2. The inner error bars comprise the statistical uncertainty in the data, and the outer error bars include all the various systematic contributions, including the error arising from the Monte Carlo statistical accuracy, added to the data statistical error in quadrature. The centre-of-mass energy is reconstructed in photoproduction from the event final state using the approximation $W_{\gamma p}^2 = ys$, where y represents the usual scaling variable and s the centre-of-mass energy squared of the incoming lepton-proton system. The cross sections are fitted using a function of the form $N(W/W_0)^\delta$ in both $|t|$-ranges. A central value of $W_0 = 90$ GeV is chosen for the fit and the statistical and uncorrelated systematic errors are included. In the low $|t|$-range the best extracted value of δ is $\delta = 0.92 \pm 0.30$, and in the high $|t|$-range $\delta = 1.15 \pm 0.55$. A similar rise in the cross section is obtained, within the larger uncertainties at large $|t|$, as previously measured for proton-elastic and proton-dissociative J/ψ production at smaller values of $|t|$ [8] and the rise is steeper than the expected effective $\delta \sim 0.22$ for soft pomeron exchange in this centre-of-mass energy range. No evidence for an increasingly steeper $W_{\gamma p}$ dependence of the cross section, however, with increasing $|t|$ can be concluded.

The same measured cross sections in both $|t|$-ranges are compared to the pQCD predictions in figure 3. The magnitude of the cross section is very sensitive to the input value of $\bar{\alpha}_s$. The predictions for an input value of $\bar{\alpha}_s = 0.221$ give a reasonable simultaneous description, within experimental errors, of both the magnitude and the shape of the measured cross sections in both $|t|$-ranges. This is similar to the expected value of $3\alpha_s/\pi = 0.18$. A small increase or decrease in the input value of $\bar{\alpha}_s$ would result in a simultaneous shift of the two predicted distributions upwards or downwards respectively. Larger values of $\bar{\alpha}_s$ lead to a steeper rise of the cross section.

5 The $|t|$ Dependence of the Cross Section.

The photon-proton differential cross section $d\sigma/d|t|$ is shown as a function of $|t|$ for the kinematic range $50 < W_{\gamma p} < 160$ GeV, $|t| > 1.0$ GeV^2 and photoproduction $Q^2 < 1.0$ GeV^2 in figure 4. The inner error bars once again comprise the statistical uncertainty in the data and the outer error bars include also all the systematic contributions added in quadrature. The measurement is in good agreement with previous measurements of the lepton-proton differential cross section [9] and the photon-proton differential cross section of the ZEUS collaboration [10]. The shape of the predicted differential cross section is not sensitive to the input value of $\bar{\alpha}_s$. The pQCD prediction for $\bar{\alpha}_s = 0.221$ is compared to the measurement and describes the $|t|$-dependence well within experimental errors, in particular for larger $|t| > 3.0$ GeV^2.

6 Summary

The differential cross-section $d\sigma/d|t|$ as a function of the momentum transfer squared $|t|$ at the proton vertex and the total cross section $\sigma(\gamma p \to J/\psi X)$ as a function of $W_{\gamma p}$ in two intervals of $|t|$ ($1 < |t| < 5\,$GeV^2 and $|t| > 5\,$GeV^2) have been measured for J/ψ production with proton dissociation in the photon-proton centre-of-mass energy range of $50 < W_{\gamma p} < 160$ GeV. The examined $|t|$-range spans the region up to $|t| = 21.0$ GeV^2. The result shows a similar hard scale behaviour as measured in previous analyses at lower values of $|t|$. Comparisons with predictions from perturbative QCD calculations show good agreement with the data.

7 Acknowledgements

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References

[1] J.R. Forshaw, M. Ryskin, Zeit. Phys. C68 (1995) 137-148.

[2] J. Bartels, H. Lotter, J.R. Forshaw and M. Wüsthoff, Phys. Lett. B375 (1996) 301-305.

[3] H. Abramovicz, T. Doeker, L. Iannotti, S. Kamanov, A. Levy, and L. West, Proc. Workshop *'Future Physics at HERA'*, eds. G. Ingelman, A. De Roeck and R. Klanner (1996) Vol. 2 pp.679-90.

[4] H1 Collaboration, Nucl. Inst. Meth. A386 (1997) 310.

[5] B. List, Diploma Thesis, Techn. Univ. Berlin, unpublished (1993);
B. List and A. Mastroberardino, Proc. Workshop *'Monte Carlo Generators for HERA Physics'* DESY, Hamburg (1999) 396.

[6] H1 Collaboration, C. Adloff *et al.*, (1998) Phys. Lett. B421 385.

[7] D. Schmidt, Ph.D. Thesis, II. Inst. Exp., Univ. Hamburg, unpublished (2001).

[8] H1 Collaboration, S. Aid *et al.*, Nucl. Phys. B472 (1996) 3.

[9] H1 Collaboration, Submitted to HEP97, Jerusalem, Israel.

[10] ZEUS Collaboration, Submitted to ICHEP 2000, Osaka, Japan.

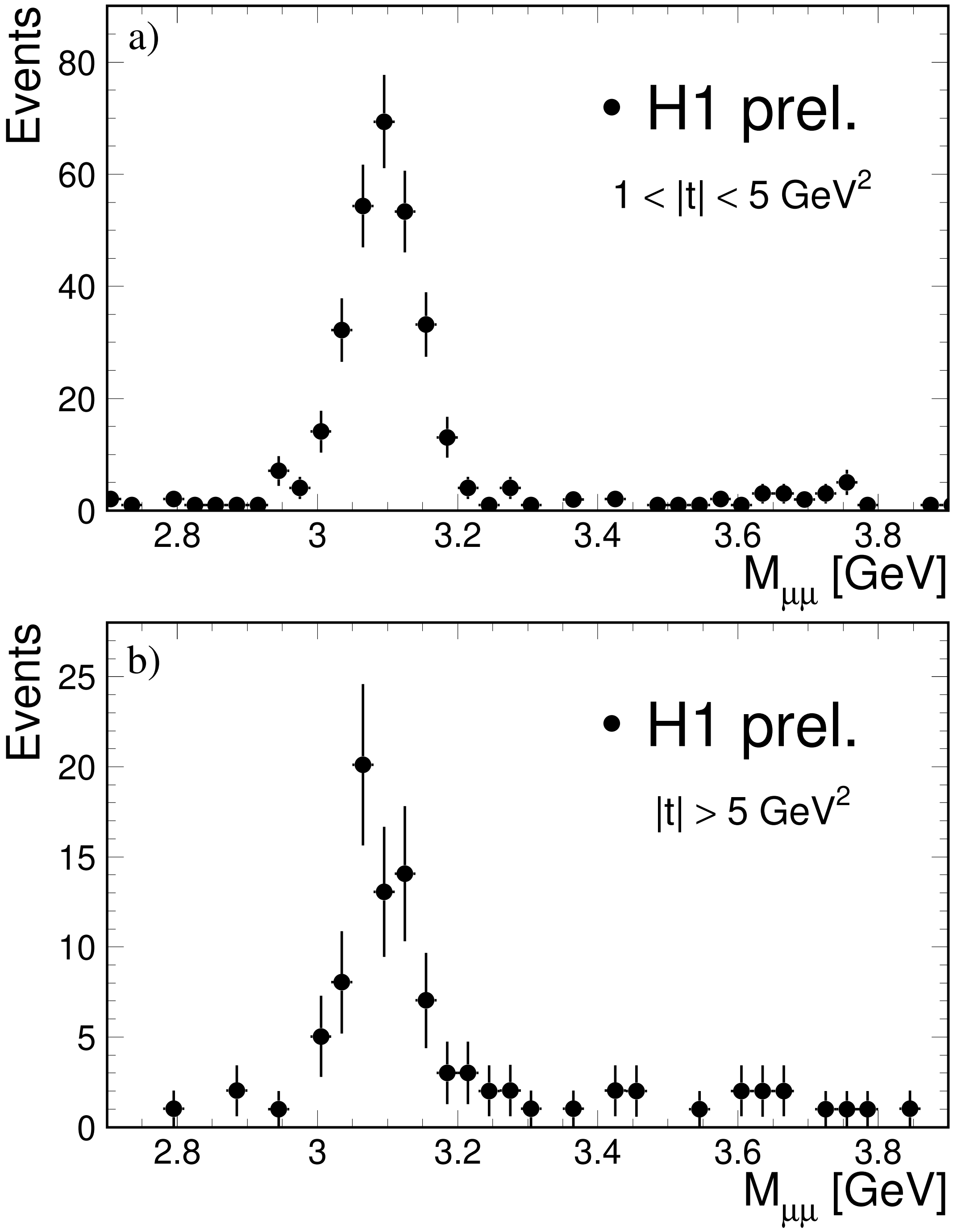

Figure 1: The invariant mass distribution of muon pairs reconstructed in the intervals a) $1.0 < |t| < 5.0\ \mathrm{GeV}^2$ and b) $|t| > 5.0\ \mathrm{GeV}^2$.

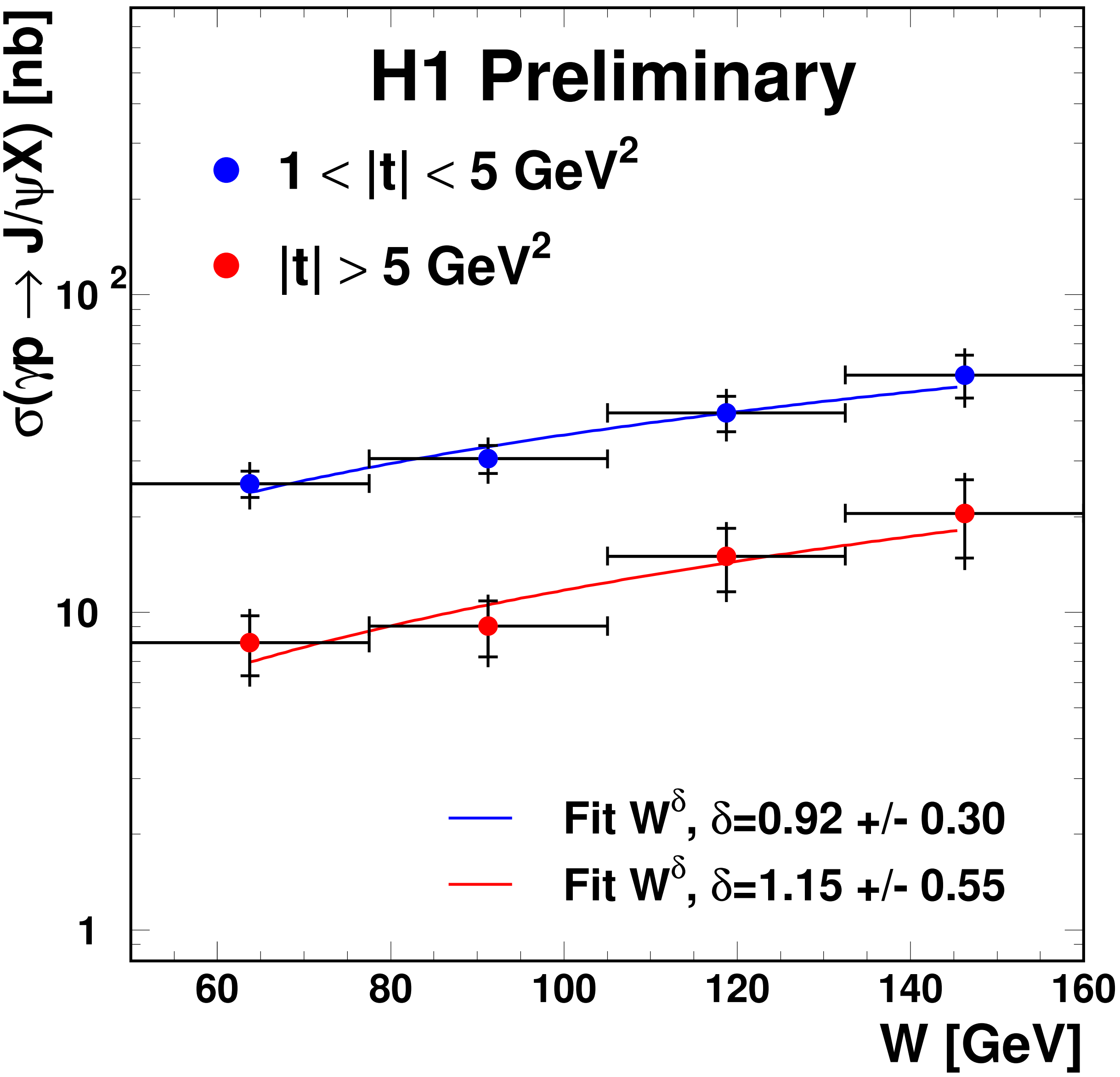

Figure 2: The photon-proton differential cross-section $\sigma(\gamma p \rightarrow J/\psi X)$ for J/ψ production with proton dissociation in the kinematic range $Q^2 < 1.0\ \mathrm{GeV}^2$ for two different intervals of $|t|$. The cross sections are fitted using a function of the form $N(W/W_0)^\delta$ where $W_0 = 90\ \mathrm{GeV}$ and show a similar rise to the cross section for J/ψ production at low $|t|$.

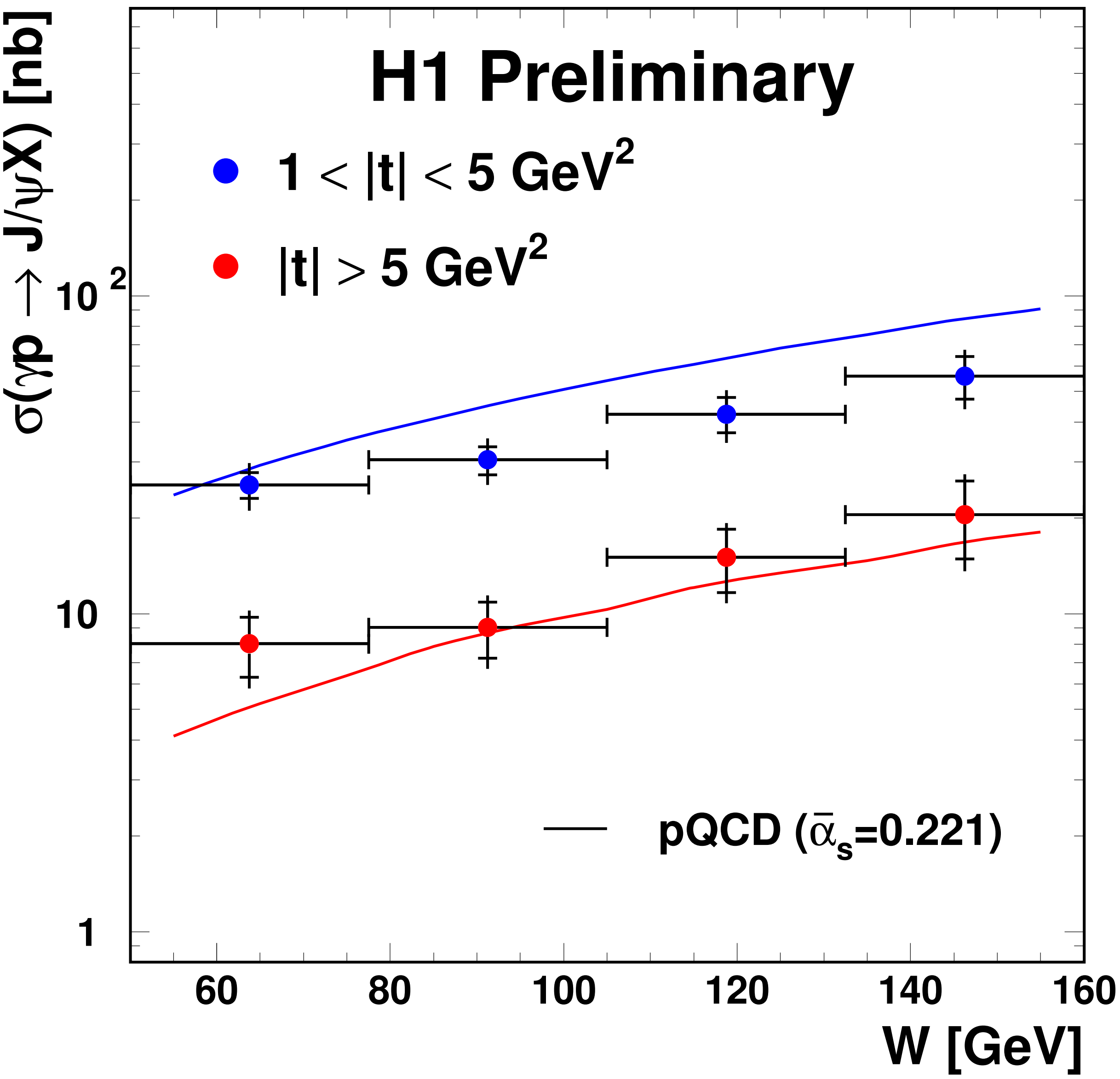

Figure 3: The photon-proton differential cross-section $\sigma(\gamma p \rightarrow J/\psi X)$ for J/ψ production with proton dissociation in the kinematic range $Q^2 < 1.0\ \mathrm{GeV}^2$ for two different intervals of $|t|$. The curves show the predictions in perturbative QCD for $\bar{\alpha}_s = 0.221$.

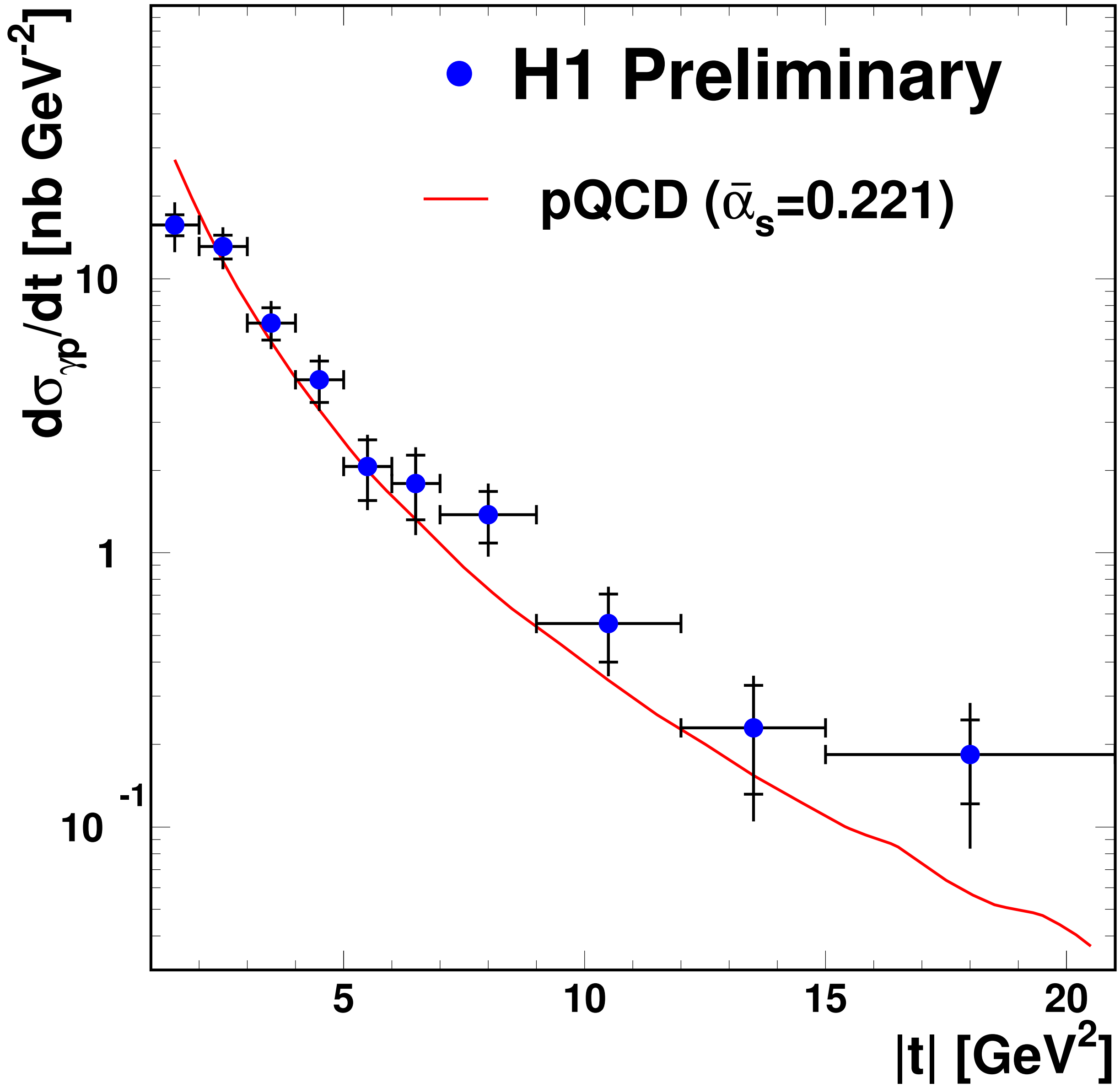

Figure 4: The photon-proton differential cross-section $d\sigma/d|t|$ for J/ψ production with proton dissociation in the kinematic range $Q^2 < 1.0\ \mathrm{GeV}^2$, $50 < W_{\gamma p} < 160\ \mathrm{GeV}$, $|t| > 1.0\ \mathrm{GeV}^2$. The measurement is compared to the prediction in perturbative QCD for $\bar{\alpha}_s = 0.221$.