CHARMONIUM PRODUCTION AT HERA USING THE H1 DETECTOR

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The diffractive production of charmonium has been studied at HERA using the H1 detector via observation of the decays of J/ψ and $\psi(2S)$ mesons. Measurements of the production cross-sections have been made in both photo-production and electro-production for both elastic and dissociative final state protons. The results are compared to models which describe the diffractive exchange within the framework of perturbative QCD.

1 Introduction

The study of diffractive charmonium production at HERA provides an ideal test of the structure of the proton and pomeron because the dominant production mechanism is sensitive to gluon structure. The large mass of the charm quark provides the hard scale to investigate the transition into the perturbative regime. The measurements can test models of the diffractive exchange based on Regge theory [1] or perturbative QCD(pQCD) [2,3]. The relevant process for this paper is

$$e(k) \;+\; p(P) \rightarrow e(k') \;+\; X(v) \;+\; Y(P') \qquad (1)$$

where X is the vector meson and Y is the final state proton. The kinematics are described by $Q^2 = -q^2 = -(k-k')^2$, $t = (q-v)^2 = (P-P')^2$, $W^2_{\gamma p} = (q+P)^2$ and $z = P\cdot v/P\cdot q$. The reaction can be either proton elastic, where Y remains a proton and the elasticity $z \approx 1$, or proton dissociative where the proton breaks up into a low mass state such that z remains close to 1. Measurements are made for both photo-production where $Q^2 \sim 0$ and electro-production where $Q > 1\,\mathrm{GeV}^2$. The results presented are based upon data taken by the H1 experiment between 1994 and 1997.

2 Photo-production of Elastic J/ψ

The photo-production of elastic J/ψ is studied by identifying the leptonic decay channel $J/\psi \rightarrow l^+l^-$ where l is either an electron or muon. Measurement of the photon-proton cross-section has been made [4] over the range($30 < W_{\gamma p} < 260\,\mathrm{GeV}$). The characteristics of models based on the 'soft' pomeron [1] are a slow rise of the cross-section with $W_{\gamma p}$, s-channel helicity conservation, and a logarithmic shrinkage of the forward elastic peak with increasing $W_{\gamma p}$. The energy dependence of the H1 data when fitted with $\sigma_{\gamma p} \propto W_{\gamma p}^{\delta}$ gives a value of $\delta = 0.77 \pm 0.13$ which is steeper than the prediction of the Regge based model.

The steep rise in the energy dependence observed in the data can be explained in perturbative QCD models which use the exchange of a gluon ladder in the leading log approximation [2]. The cross-section (in leading order) is proportional to the square of the gluon density of the proton and therefore the strong rise of the cross-section with $W_{\gamma p}$ is coupled to the rising gluon content at low x .

For small values of $|t|$, the cross-section is found to have an exponential t dependence and a fit to $\sigma \propto \exp^{-b|t|}$ gives a value of $b = 4.1 \pm 0.2 \pm 0.2\,\mathrm{GeV}^{-2}$. The H1 data are consistent with both shrinkage and a flat dependence of this elastic slope with $W_{\gamma p}$. Hence the HERA measurements alone cannot yet make a strong statement on the evidence for shrinkage. The measured decay angular distributions of the J/ψ are found to be consistent with s-channel helicity conservation.

3 Electro-Production of Elastic J/Ψ

Elastic electro-production of J/ψ mesons has been measured as a function of $W_{\gamma p}$ and Q^2(see figure 1). The measured slope of the $W_{\gamma p}$ dependence is $\delta \simeq 1$, which is consistent with that measured in photo-production. The dependence of the cross-section on Q^2 is parameterised in the form $(Q^2 + m^2_{J/\psi})^{-n}$ and gives a value of $n = 2.24 \pm 0.19$ consistent with other vector mesons. The dependence on both $W_{\gamma p}$ and Q^2 is well described by a model based upon pQCD[3]. The slope parameter of $d\sigma/dt$ is determined for elastic J/ψ production as $b^{el} = 3.9 \pm 0.4\,(\mathrm{stat}) \pm 0.4\,(\mathrm{syst})\,\mathrm{GeV}^{-2}$, compatible with the result obtained in photoproduction.

A first study of the helicity structure of J/ψ production at large Q^2 at HERA has been made by observation of the decay angular distribution. No hint of a possible violation of the s-channel helicity conservation hypothesis is found. Fits with $R = \sigma^L/\sigma^T$ as a free parameter have been performed and yield for the $\cos\theta^*$ distribution $R = 0.34^{+0.27}_{-0.19}$ indicating a rise of R with Q^2.

4 Photo-production of J/ψ with Proton Dissociation at large t

J/ψ production has been studied in photo-production when the proton dissociates [5] and $|t| > 1\,\mathrm{GeV}^2$ in the range of $30 < W_{\gamma p} < 150\,\mathrm{GeV}$. The differential cross-sections $\mathrm{d}\sigma_{ep}/\mathrm{d}p_t^2$ (figure 2(b)) and $\mathrm{d}\sigma_{ep}/\mathrm{d}W_{\gamma p}$ have been determined. For large $|t|$, predictions from a perturbative QCD model [6] using the BFKL evolution equations are compared to the data. The one free parameter in this leading order calculation is the fixed value of the strong coupling constant $\overline{\alpha}_s$. The preferred value of $\overline{\alpha}_s$, which gives good agreement with the data in both the t and $W_{\gamma p}$ dependences for the pQCD model, is found to be $\overline{\alpha}_s = 0.207 \pm 0.007$.

5 Electro-production of Quasi-Elastic $\psi(2S)$

The first observation at HERA of $\psi(2S)$ at large Q^2 has been made. Due to limited statistics no distinction is made between proton elastic and proton dissociative processes so a quasi-elastic cross-section is defined for $z > 0.95$. The ratio of the cross-sections for the quasi-elastic production, $\sigma^{\psi(2S)}_{\gamma^* p}/\sigma^{\psi}_{\gamma^* p}$, is extracted as a function of Q^2(figure 2(a)). At small Q^2 the result agrees with the previous H1 result obtained in photoproduction [7], while an indication for a rise at higher Q^2 is observed which is consistent with theoretical predictions [8] based on careful treatment of the wave-functions in QCD.

6 Conclusion

Charmonium production at HERA has been studied via the observation of J/ψ and $\psi(2S)$ mesons. Measurements have been made for both photo-production and electro-production and for when the proton remains intact or dissociates. Predictions from models of diffractive exchange using pQCD are found to give good agreement with the H1 measurements.

References

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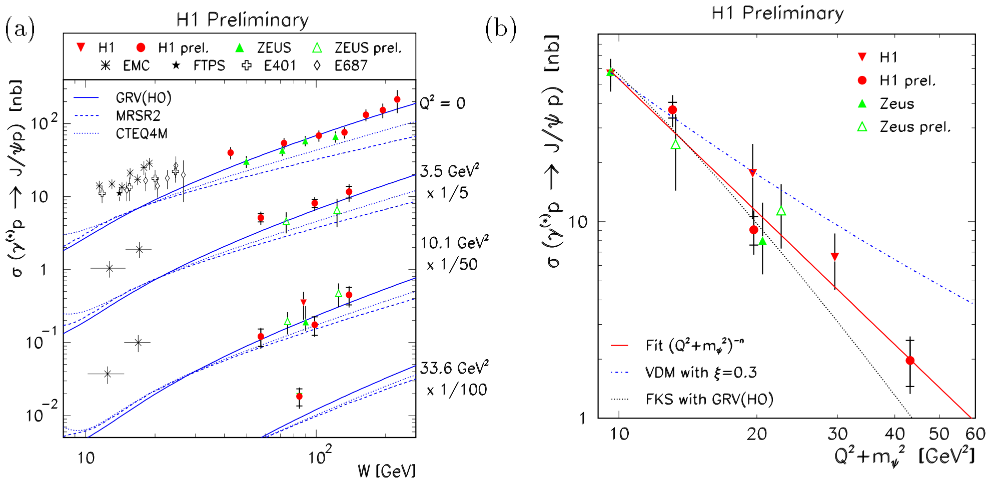

Figure 1: Cross-sections measured at HERA and in fixed target experiments for elastic J/ψ production as a function of (a) $W_{\gamma p}$ in different domains of Q^2. Data at $Q^2 > 0$ have been scaled by factors 5,50,100 as indicated. The lines are results of calculations from Frankfurt, Koepf and Strikman [3] for several recent parton distributions (b) $Q^2 + m_\psi^2$ at $W = 90 GeV$ The full line is a fit of the form $(Q^2 + m_\psi^2)^{-n}$. The dotted line is a result by Frankfurt, Koepf and Strikman [3]. The dash-dotted line is a VDM parameterisation.

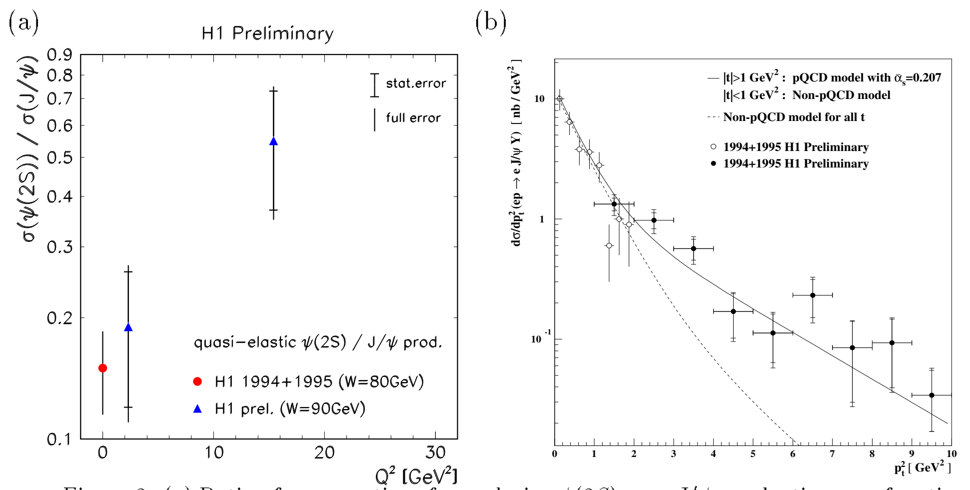

Figure 2: (a) Ratio of cross sections for exclusive $\psi(2S)$ over J/ψ production as a function of Q^2 (b) The differential electron-proton cross-section measurements for J/ψ production with proton-dissociation as a function of p_t^2 where the dashed line is the expectation from a single exponential fitted to the low $|t|$ data and the solid line is the prediction from a pQCD model using the BFKL formalism [6].