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DIFFRACTIVE PHOTOPRODUCTION OF $\psi(2S)$ MESONS AT HERA*

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The diffractive photoproduction of the $\psi(2S)$ meson is measured using a data set collected between 1996 and 2000 by the H1 detector at HERA corresponding to a luminosity of $77\,\mathrm{pb}^{-1}$. The ratio of the integrated diffractive cross sections for $\psi(2S)$ and J/ψ production is presented as a function of the photon–proton centre-of-mass energy $W_{\gamma p}$. The dependences of elastic and proton-dissociative $\psi(2S)$ production on the four-momentum transfer squared t at the proton vertex are also presented. The results are compared to theoretical predictions calculated within the colour dipole framework.

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1. Introduction

The $\psi(2S)$ meson is the first radial excitation of the J/ψ meson and the expectation value of its radius is approximately a factor two larger than that of the J/ψ meson. Predictions for the $|t|$ and $W_{\gamma p}$ dependencies of the diffractive $\psi(2S)$ and J/ψ production cross sections have been completed in the framework of the colour dipole model. In this model the incoming photon is assumed to fluctuate into a $q\overline{q}$ pair, modelled as a colour dipole, some long time before interacting with the proton. The elastic scattering of the parent dipole with the proton is then parameterised by a total dipole–proton cross section. The wavefunction of the $\psi(2S)$ meson has a larger expectation value for the radius than the ground J/ψ state but also has a node (see *e.g.* [1]). This leads to cancelling contributions from dipoles with sizes above and below the node. The total cross section for $\psi(2S)$ meson production is then suppressed with respect to that of J/ψ and the

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dependence of the cross section as a function of $W_{\gamma p}$ is somewhat steeper than that of the J/ψ photoproduction cross section. The t-dependence of elastic $\psi(2S)$ production is predicted to be similar or slightly steeper than that of the J/ψ meson [2].

2. Event selection and data analysis

The diffractive production of the $\psi(2S)$ meson is measured using a data set collected between 1996 and 2000 by the H1 detector at HERA corresponding to a luminosity of 77 pb^{-1} [3]. The kinematic region of photoproduction (photon virtualities $Q^2 < 1.0\,\mathrm{GeV}^2$) is selected by rejecting events which contain a scattered lepton candidate detected in the calorimeters. The H1 Detector is described in detail elsewhere [4]. The $\psi(2S)$ and J/ψ mesons are selected via their direct decays into two leptons $\mu^+\mu^-$ or e^+e^- and the $\psi(2S)$ is also reconstructed via the cascade into a J/ψ and two charged pions with subsequent decay of the J/ψ into two leptons. The lepton-pair decay signatures are selected by requiring exactly two tracks in the central tracking chambers, each with a transverse momentum greater than 0.8 GeV in the central polar angular region of the detector. The tracks must define an event vertex in the ep interaction region. The decay electrons are identified using the electromagnetic section of the calorimeters and energy loss dE/dx in the tracking chambers. Muons are identified in the instrumented iron return yoke of the main solenoidal magnet or in the main calorimeter. Cosmic ray muon events are rejected using a track acollinearity requirement. For the selection of $\psi(2S)$ cascade decay events exactly four tracks are selected. In addition to two lepton candidate tracks, which are identified as described above, exactly two further central tracks of opposite charge are required, each with a transverse momentum of at least 0.12 GeV. Triggers based on lepton and track signatures are used to collect the events. The acceptances and efficiencies for triggering, track reconstruction, event selection and lepton identification are calculated using the Monte Carlo event generator program DIFFVM [5]. The overall efficiency for the combined decay channels varies between 5 and 10% with $W_{\gamma p}$. In the range studied here the variation of the overall efficiency with $|t|$ is small.

3. Results

The ratio of the integrated elastic and proton dissociative[1] diffractive cross sections for $\psi(2S)$ and J/ψ production is shown as a function of the photon–proton centre-of-mass energy $W_{\gamma p}$ in Fig. 1. The error bars exclude

[1] Events are selected in which the proton (mass m_p) dissociates into a mass M_Y fulfilling the relationship $z \simeq 1 - (M_Y^2 - m_p^2 - t)/W_{\gamma p}^2 > 0.95$.

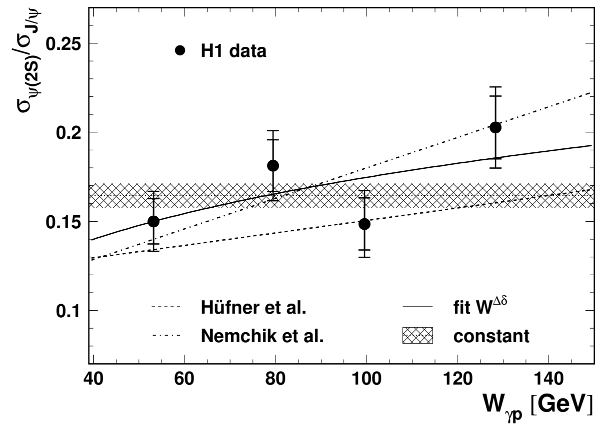

Fig. 1. The ratio $R(W_{\gamma p}) = \sigma_{\psi(2S)}/\sigma_{J/\psi}$ for events with $z > 0.95$. The inner error bars show the statistical error, the outer error bars show the statistical and systematic errors added in quadrature. The result of a fit $R \propto (W_{\gamma p}/90\,\mathrm{GeV})^{\Delta\delta}$ is shown by the solid line and the predictions from [2] (dashed–dotted line) and [1] (dashed line) are also shown.

the normalisation uncertainty of 0.007 from the branching ratios. The number of J/ψ events is corrected for the fraction of $\psi(2S)$ events with decays into a J/ψ and undetected neutral particles. The contribution to the $\psi(2S)$ sample from decays of $\psi(3S)$ and higher excited states is expected to be small and is neglected. In the evaluation of the systematic error on the cross section ratio the errors on the integrated luminosity, the trigger and track reconstruction efficiencies, lepton identification and the detector acceptance are found to be highly correlated between the J/ψ and the $\psi(2S)$ samples and, therefore, largely cancel. The average ratio, shown as a dotted line, yields the value

$$R = 0.166 \pm 0.007(\mathrm{stat.}) \pm 0.008(\mathrm{syst.}) \pm 0.007(\mathrm{BR})\,,$$

in good agreement with an earlier measurement [6]. The solid line shows a fit of the form $R(W_{\gamma p}) \propto W_{\gamma p}^{\Delta\delta}$ to the data points yielding a value of $\Delta\delta = 0.24 \pm 0.17_{\mathrm{stat.+sys.}}$. In the context of this analysis a complete measurement of the J/ψ cross section was also performed [7], yielding a $W_{\gamma p}$ dependence which is consistent with the results of [8].

The elastic and proton-dissociative t-dependencies are extracted in each decay channel using an iterative procedure involving fits to the forward-tagged and forward-untagged samples. Fig. 2 shows the normalised differential cross sections $1/\sigma\, d\sigma/dt$ for the lepton-pair and cascade decay signatures of $\psi(2S)$ events in a mass window $\pm$ 150 MeV around the nominal $\psi(2S)$ mass, corrected for efficiencies but not for remaining backgrounds.

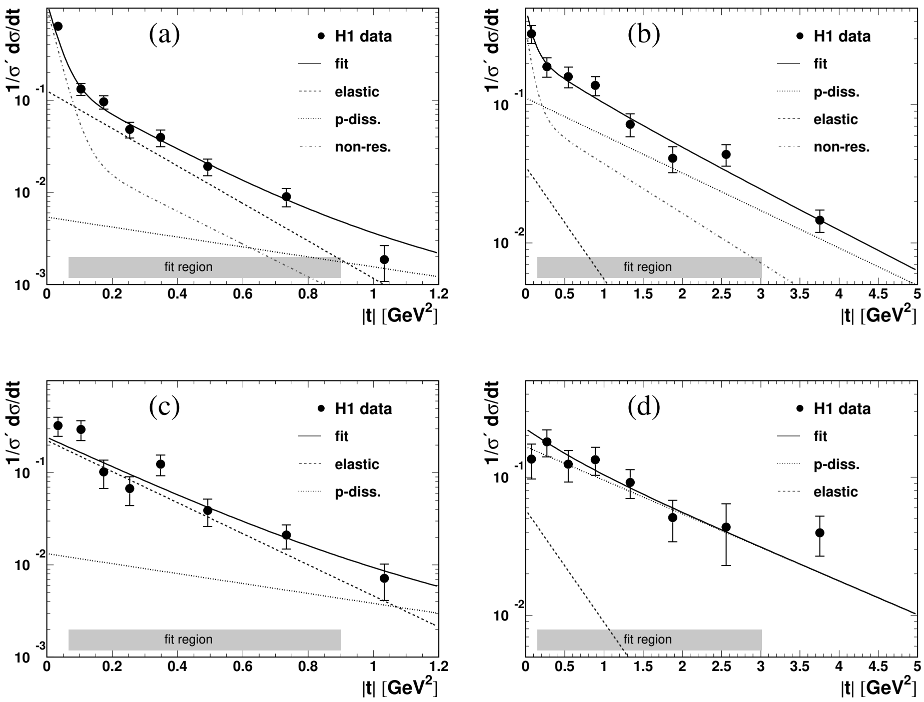

Fig. 2. Normalised differential cross sections $1/\sigma\, d\sigma/dt$ as a function of $|t|$ for events in the $\psi(2S)$ mass region (a) without and (b) with a forward-tag for lepton-pair decays and (c) without and (d) with a forward-tag for cascade decays. The solid lines show the results of the fits described in the text. The dashed (dotted) curves show the contributions from the elastic (proton dissociative) processes respectively and the contributions from the non-resonant background (dashed–dotted curves) are also shown. The shaded bands indicate the region in which the fit is performed.

The main contributions to the samples are from the proton-dissociative and elastic process plus non-resonant background in the two-prong channel. The non-resonant backgrounds are described by sums of two exponential functions determined from an analysis of the side-band events. The t-dependence and relative normalisation of the non-resonant backgrounds are held fixed. The t-dependences of the elastic and the proton dissociative channels are parameterised by single exponential functions $\sim e^{bt}$. The measured slope parameters are $b_{\rm el}^{\psi(2S)} = (4.31 \pm 0.57 \pm 0.46)\,{\rm GeV}^{-2}$ and $b_{\rm pd}^{\psi(2S)} = (0.59 \pm 0.13 \pm 0.12)\,{\rm GeV}^{-2}$ for elastic and proton-dissociative $\psi(2S)$ production. For the J/ψ the result $b_{\rm el}^{J/\psi} = (4.99 \pm 0.13 \pm 0.39)\,{\rm GeV}^{-2}$ confirms the previous measurement [8] and $b_{\rm pd}^{J/\psi} = (1.07 \pm 0.03 \pm 0.11)\,{\rm GeV}^{-2}$.

4. Comparison with models

The calculations of [1] and of [2] both predict a somewhat steeper energy dependence for the $\psi(2S)$ than for the J/ψ meson and are compatible with the data in both slope and normalisation. The t-dependence of elastic $\psi(2S)$ photoproduction is in agreement with expectations in the additive quark model [9] and the colour dipole model [2] where the difference between the J/ψ and $\psi(2S)$ proton dissociative slope parameters can be interpreted as an effect of the $\psi(2S)$ wavefunction node on the t-dependence. In proton dissociation this is more visible than in the elastic process due to the lower overall values of the slope parameters in agreement with expectations [9].

5. Summary

The energy dependence of the diffractive $\psi(2S)$ photoproduction cross section is similar or possibly slightly steeper than that for J/ψ mesons. The t-dependence of elastic $\psi(2S)$ photoproduction is similar to that of the J/ψ. For proton dissociation a somewhat shallower t-dependence is measured in the $\psi(2S)$ case. The results are in agreement with the expectations of colour dipole model predictions which incorporate the effect of the node in the $\psi(2S)$ wavefunction.

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