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Diffractive $\psi(2S)$ Photoproduction at HERA

H1 Collaboration

Abstract

The elastic photoproduction of $\psi(2S)$ mesons is analyzed using data collected between 1996 and 1999 with the H1 detector at the HERA collider. The data sample corresponds to an integrated luminosity of about ~ 38 pb^{-1}. The $\psi(2S)$ mesons are identified through their leptonic decay. The t-dependence of the elastic $\psi(2S)$ production differential cross section is compared to that of J/ψ production, and the slope, parameterized as $e^{-b|t|}$, is measured to be $b = 4.5 \pm 1.2\ ^{+1.4}_{-0.7}$ GeV^{-2}.

Abstract: 987, 985
Parallel sessions: PA-02, 07
Plenary sessions: PL-12, 03

Introduction

The cross section of elastic J/ψ meson photoproduction, $\gamma p \to J/\psi\, p$, at HERA energies has been measured to rise steeply with increasing energy [1]. This is interpreted as a signature for a short distance process [2, 3] due to the small transverse size of the $c\bar{c}$ system. The "size" of the $c\bar{c}$ system is related also to the dependence of the cross section on t, the square of the 4-momentum transfer at the proton vertex. Smaller systems are expected to have a less peripheral t-dependence. The t-slope, that is the value of b in a parametrisation of the differential production cross section $\frac{\mathrm{d}\sigma}{\mathrm{d}t} \propto e^{-b|t|}$, has indeed been measured to be much smaller for the J/ψ [1] than for elastic ρ meson production [4].

The $c\bar{c}$ radial excitation $\psi(2S)$ has a larger radius than the ground state J/ψ and its radial wave function has a node. In a QCD calculation this leads one to expect two distinct features for elastic $\psi(2S)$ photoproduction [7]. Firstly, the cross section should be suppressed compared to that of the J/ψ. This has been measured [5][1]. Secondly, the t-slope should be roughly equal to or smaller than that of the J/ψ, even though the two c-quarks are on average further apart than in the ground state.

Here we present a first measurement of the t-dependence of $\psi(2S)$ photoproduction.

Data Analysis

The analysis presented here is based on data with an integrated luminosity of $\int \mathcal{L}\,\mathrm{dt} \sim 38\,\mathrm{pb}^{-1}$. The data were taken in the period 1996 – 1999. In 1996 and 1997 HERA was operated with positrons of 27.5 GeV and protons of 820 GeV, while in 1999 the proton energy was 920 GeV, and electrons and positrons were used. The analysis is carried out in the photoproduction limit, i.e. $Q^2 \lesssim 1\,\mathrm{GeV}^2$, and covers a range of photon proton center of mass energies of $40 < W_{\gamma p} < 150\,\mathrm{GeV}$.

For the analysis the direct leptonic decays $\psi(2S) \to \mu^+\mu^-, e^+e^-$ are used. Events in which $\psi(2S)$ decays into a J/ψ and two charged pions with subsequent decay of the J/ψ into two leptons have also been analyzed. As the transverse momentum of the cascade decay pions is low, the experimental uncertainty in the cascade decay channel is large in comparison to the direct leptonic decay of the $\psi(2S)$. Therefore the cascade decay events were only used for cross check purposes.

The data selection resembles closely the procedure used for detecting the J/ψ described in detail e.g. in [1]. Exactly two tracks each with a transverse momentum greater than $800\,\mathrm{MeV}$ are required in the central tracking chambers in a polar angular range of $20^\circ < \theta < 160^\circ$[2]. Both tracks have to fit to the event vertex and satisfy the lepton identification requirements.

Electrons are identified using the electromagnetic part of the LAr calorimeter and energy loss in the tracking chamber. In addition, the backward electromagnetic calorimeter Spacal is used

[1] see however [6].

[2] The coordinate system of H1 defines the positive z axis to be in the direction of the incident proton beam. The polar angle θ is then defined with respect to the positive z axis.

at large polar angles. Muons are identified as minimum ionizing particles in the calorimeter or in the instrumented iron return yoke [8, 9]. Events are rejected if a scattered beam lepton candidate with more than $8\,$GeV energy deposit is detected in the calorimeter. The accepted event sample thus fulfills $Q^2 \lesssim 1\,$GeV^2 with an average $\langle Q^2 \rangle \sim 0.05$ GeV^2.

In order to separate the elastic process from that with dissociation of the proton to a small mass system, the forward part of the calorimeter ($\theta < 10°$) and detectors covering polar angles close to the proton beam ($0.06° < \theta < 0.26°$ and $3° < \theta < 17°$) are used. With these detectors proton remnants with masses $M \gtrsim 1.6\,$GeV can be detected. Events without any signal in the forward counters are called the "forward untagged" sample.

Fig. 1 shows the mass distribution of the combined forward tagged and untagged samples. The insert shows the mass distribution restricted to the $\psi(2S)$ region. The non-resonant background is dominated by the process $\gamma\gamma \to l^+l^-$.

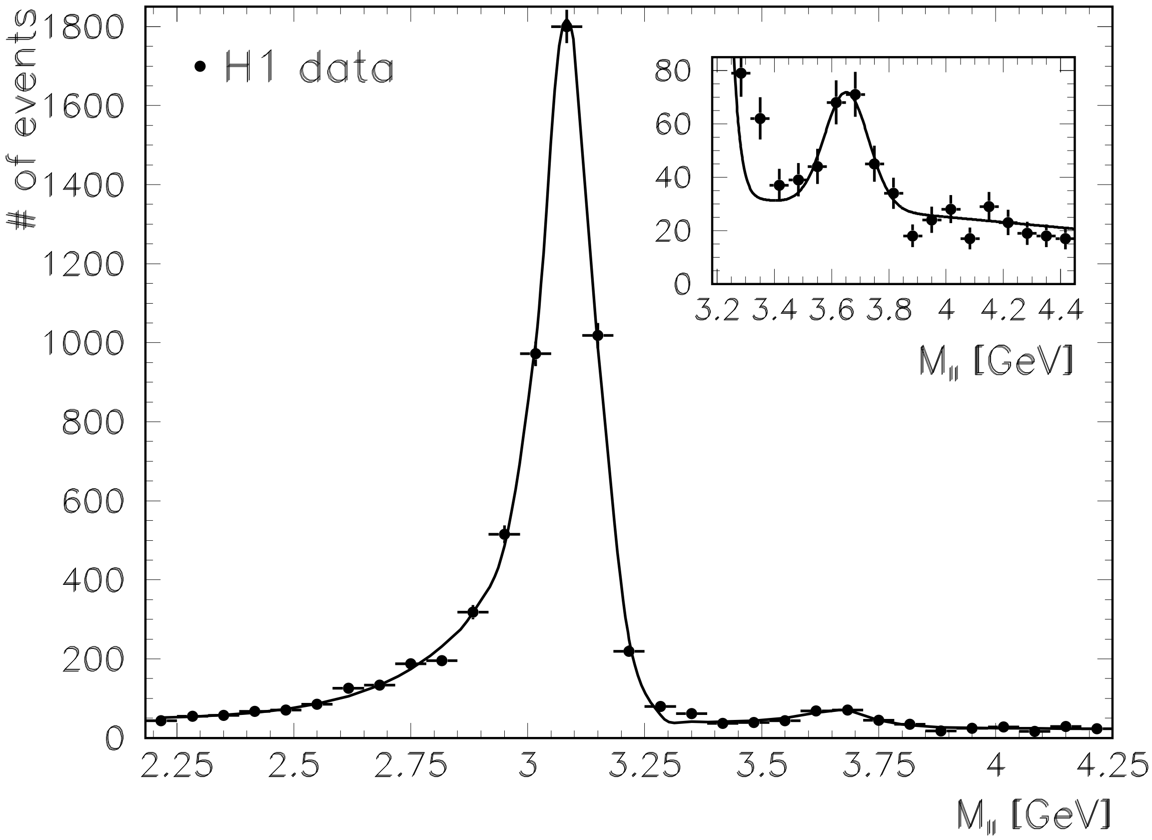

Figure 1: Mass spectrum of the whole data sample for both decay channels from 1996, 1997 and 1999 for $|t| > 0.07\,$GeV^2. The insert shows the mass distribution restricted to the $\psi(2S)$ region. The curve is fitted combining a Gaussian and an exponential for the radiation tail from the electron decay channel for the vector meson resonances with a linear polynomial for the background.

The t Dependence for Elastic $\psi(2S)$ Production

In elastic vector meson photoproduction events the variable t can be approximated by $t \simeq -(\vec{p_t})^2$, where $\vec{p_t}$ is the transverse momentum of the vector meson. The t-dependence of $\psi(2S)$ production is measured averaging over the entire $W_{\gamma p}$ range of $40 < W_{\gamma p} < 150$ GeV. The resolution in t was estimated with the help of the Monte Carlo generator DIFFVM [10] which simulates elastic and proton dissociative vector meson production. For the muonic decay channel a value of typically 0.035 GeV^2 was found which increases to $0.060\,\mathrm{GeV}^2$ for $|t| \approx 1.2\,\mathrm{GeV}^2$. For the electron decay channel the resolution is roughly 15% worse due to bremsstrahlung.

Fig. 2 shows the ratio between the measured number of events in the region of $150\,\mathrm{MeV}$ around the nominal $\psi(2S)$ mass and the number of events in the J/ψ signal as a function of $|t|$. The contribution from non-resonant background is determined from a fit to the sidebands of the data and statistically subtracted. Only events without a signal in the forward detectors are used. No correction for detector acceptance or efficiencies is applied here as the corrections for J/ψ and $\psi(2S)$ events are very similar. The slope of the ratio as a function of t is consistent with zero, indicating that $\psi(2S)$ and J/ψ meson production have similar t-dependences. Note that the background contributions from proton dissociation processes increase towards high values of $|t|$ for both J/ψ and $\psi(2S)$ production. Although these contributions are similar and thus largely cancel in the ratio, the interpretation of fig. 2 should be taken with care.

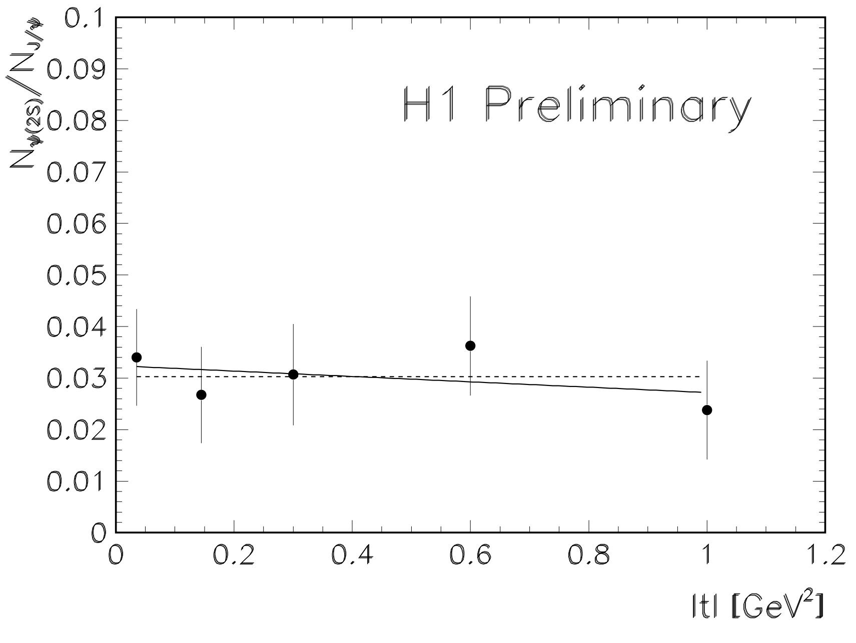

Figure 2: Uncorrected ratio of the number of forward untagged events in the region $150\,\mathrm{MeV}$ around the nominal $\psi(2S)$ mass subtracting the sidebands over the number of J/ψ as a function of $|t|$. The two curves are derived from fits to the data points assuming a constant (dashed line) and a linear (solid line) behavior respectively.

The t-dependence is measured using all forward untagged events in a mass window of $\pm$ 150 MeV around the nominal mass of the $\psi(2S)$ and dividing these into bins of t. The data points shown in fig.3 are corrected for detector acceptance and efficiencies. With this selection the untagged data sample contains 39% of elastic $\psi(2S)$ events, 6% of events with proton dissociation and 55% of non-resonant background. The contribution of $\psi(3S)$ to this data sample is expected to be approximately four orders of magnitude smaller than the $\psi(2S)$ contribution.

The t-dependence of the elastic $\psi(2S)$ events is extracted through a fit taking the three contributions in the forward untagged data sample into account. A single exponential $e^{-b|t|}$ is assumed to describe the elastic cross section averaging over the measured $W_{\gamma p}$ range. The background from proton dissociative events is described by another single exponential. The contribution of this background is determined from data using tagged events and correcting for the difference between tagged events and untagged events in proton dissociation using Monte Carlo simulations of events generated with DIFFVM [10]. The non-resonant background is described by a sum of two exponential functions which are obtained by fitting the t-distribution of the sidebands. A comparison of the exponents extracted from the LPAIR generator program [11] which simulates the non-resonant background shows good agreement. The only free parameters in this fit are the elastic slope parameter b and a normalization parameter. The first and the last t-bin are not included in the fit as in these bins the background dominates over the elastic component.

The fit yields

$$b = (4.5 \pm 1.2 \ {}^{+1.4}_{-0.7}) \ \mathrm{GeV}^{-2}.$$

The first value reflects the statistical and the second the systematic uncertainty. The systematic uncertainty is determined by varying the fractions of the non-resonant and the dissociative background contributions. To estimate the effect from uncertainties on detector acceptance and efficiencies, the Monte Carlo simulation is used with different t-dependences. In addition, the same fit is performed including the first and the last bin and for the electron and muon sample separately. The systematic error contains the differences summed in quadrature separately for the up and the down variations.

The result is consistent with the slope parameter of the J/ψ meson of $(4.73 \pm 0.25 \ {}^{+0.30}_{-0.39})$ GeV^{-2} measured in [1].

Summary

The measurement of the t-dependence of the elastic production differential cross section $\frac{d\sigma}{dt}$ of the $\psi(2S)$ meson in a range of $40 < W_{\gamma p} < 150$ GeV and $Q^2 \lesssim 1$ GeV^2 has been reported. The exponent b, when an exponential fit is made to the t-dependence of $\frac{d\sigma}{dt} \propto e^{-b|t|}$, is found to be consistent with the value measured for the J/ψ meson,as expected in QCD calculations.

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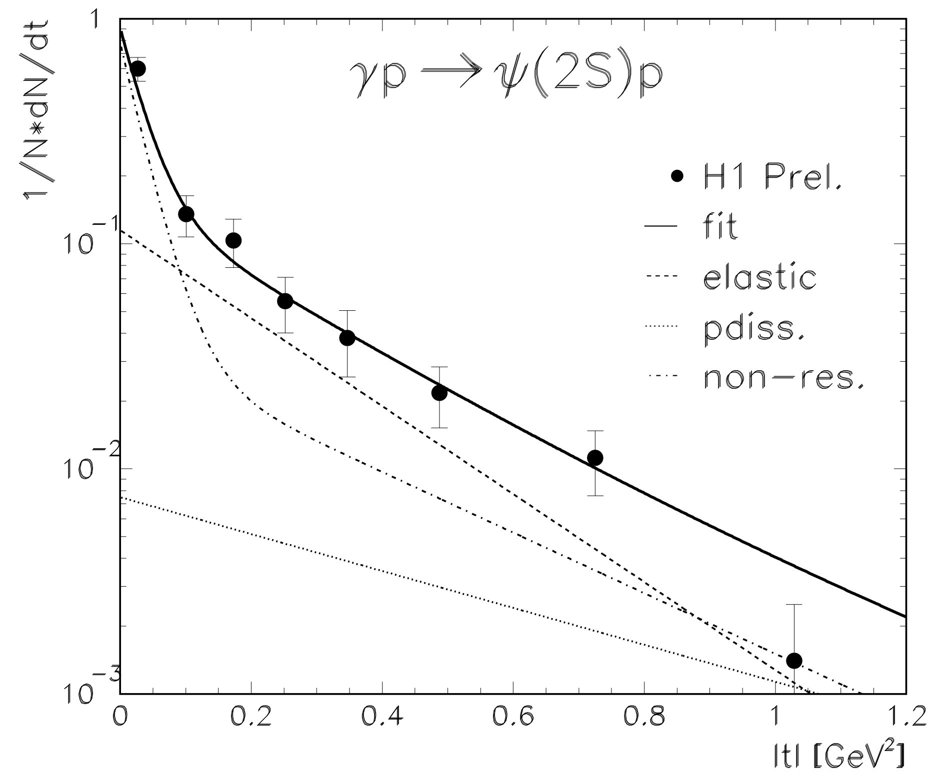

Figure 3: The corrected number of events $1/N \cdot dN/dt$ for untagged events around the $\psi(2S)$ mass as a function of $|t|$ and averaged over $40 < W_{\gamma p} < 150\,$GeV. The lines correspond to different contributions to the combined fit of the t-slope. The fit excludes the first and last data point and is described in detail in the text.

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