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Elastic Production of J/ψ Mesons in Photoproduction and at High Q^2 at HERA

H1 Collaboration

Abstract

The elastic production of J/ψ mesons, i.e. the reaction $ep \to eJ/\psi p$ has been studied with the H1 detector in two regions of the photon virtuality Q^2. Data are presented for photoproduction, $Q^2 \sim 0$, where the measurements have been extended to higher $W_{\gamma p}$, the center of mass energy of the photon–proton collision. The dependence of the differential cross section on the square of the momentum transfer from the proton t, has been measured in this extended range. For $Q^2 > 2$ GeV^2 new results are given for the cross section as a function of Q^2 and as a function of $W_{\gamma p}$.

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Introduction

Previous H1 results [1, 2] concerning elastic photoproduction of J/ψ mesons (that is $ep \to e\, J/\psi\, p$ with the virtuality of the exchanged photon $Q^2 \sim 0$) and at large Q^2 ($8 < Q^2 < 40\,\mathrm{GeV}^2$) have shown the following results:

Elastic **photoproduction** of J/ψ mesons shows features of a diffractive process, namely an exponential t distribution at low t ($t = (p - p')^2$, where p and p' are the four momenta of the incoming and scattered proton) and transverse polarisation of the J/ψ in agreement with s-channel helicity conservation. However the the cross section was found to increase much more with increasing photon-proton center of mass (cms) energy $W_{\gamma p}$ than predicted in diffractive models, e.g. by Donnachie and Landshoff [3].

In **electroproduction** the Q^2 dependence of the cross section can be parameterized as $1/(Q^2 + m_\psi^2)^n$ with $n \simeq 2$. The t distribution shows an exponential fall-off with a slope comparable to results for J/ψ photoproduction. The cross section increases strongly with $W_{\gamma p}$ from the fixed target [4] to the HERA region.

We report here on updates of the previous analyses in the two Q^2 regions using data taken in 1995 with an upgraded detector. Due to a new electromagnetic calorimeter (SpaCal) and a new driftchamber in the backward region [5] the analysis of photoproduction data is extended into the high $W_{\gamma p}$ region ($120 < W_{\gamma p} < 240\,\mathrm{GeV}$). For electroproduction the lower Q^2 region, $2 < Q^2 < 8\,\mathrm{GeV}^2$, is accessible.

Event Selection

The selection of elastic J/ψ events is carried out as described in [1, 2]. For $W_{\gamma p} \leq 150\,\mathrm{GeV}$ exactly two tracks fitted to the event vertex are required in the central tracking chambers [6] in the polar angle range $20° < \theta < 160°$, where θ is measured with respect to the proton direction. At high Q^2 at least one of the leptons has to be identified as either an electron or a muon; for photoproduction both leptons are identified. To reject events in which the proton dissociates detectors covering polar angles close to the proton beam ($0.06 < \theta < 0.17°$ and $3 < \theta < 17°$) are utilized.

In order to increase the range in $W_{\gamma p}$ in the photoproduction analysis the new backward calorimeter is utilized. This device is used to trigger, identify and reconstruct electrons or positrons from the decay $J/\psi \to e^+e^-$. Its angular coverage ($155° < \theta < 177°$) allows electrons to be detected at larger polar angles than analyses that use only the tracking detectors and thus enables the high $W_{\gamma p}$ region to be explored. J/ψ candidates are selected by requiring, in addition to an SpaCal electromagnetic energy cluster in SpaCal with $E > 4$ GeV, exactly one track in the central tracker. The mass distribution of the selected events is shown in figure 1; a J/ψ signal is observed with little background.

For the measurements of elastic J/ψ production at larger Q^2 the scattered positron is identified through the detection of an electromagnetic cluster with an energy of at least $12\,\mathrm{GeV}$ in the backward calorimeter.

Results

The calculation of the cross section proceeds as in [1, 2]. The observed number of events is corrected for non-resonant background and for remaining contributions from proton dissociation. After correcting for acceptance and efficiencies the ep cross section is calculated. It is converted into a γp ($\gamma^* p$) cross section using the Weizsäcker-Williams approximation.

Elastic Photoproduction of J/ψ Mesons

The cross section for elastic photoproduction of J/ψ mesons as a function of $W_{\gamma p}$ is shown in figure 2 together with data from [2] at $W_{\gamma p} \leq 120\,\mathrm{GeV}$. The systematic error is estimated as in previous analyses, the main contributions are due to the subtraction of the background from proton dissociation and the knowledge of trigger efficiencies. A fit of the form $W_{\gamma p}^{\delta}$ to the H1 data between $30 \leq W_{\gamma p} \leq 240\,\mathrm{GeV}$ yields a value of $\delta = 0.77 \pm 0.13$ (including statistical and systematic errors). This increase with $W_{\gamma p}$ is steeper but compatible with the H1 measurements below 150 GeV, where $\delta \sim 0.6$ was observed. This rise with $W_{\gamma p}$ is much steeper than the prediction of the Regge motivated Donnachie-Landshoff model ($\delta \simeq 0.32$).

The momentum transfer t can be approximated by $-p_t^2$ for photoproduction. The p_t^2 distribution is fitted by an exponential $\exp(-bp_t^2)$ in the range $0 \leq p_t^2 \leq 1\,\mathrm{GeV}^2$. The Donnachie-Landshoff model predicts "shrinkage", namely a logarithmic increase of the b slope with $W_{\gamma p}$:

$$b = b_0 + 2\alpha' \ln W_{\gamma p}^2 / W_0^2.$$

where $\alpha' = 0.25$ and b_0 is the slope at $W_{\gamma p} = 0$. The b slope is evaluated in four $W_{\gamma p}$ bins. Fits to the distributions of p_t^2 below $1\,\mathrm{GeV}^2$ yield b–values of the order of $4\,\mathrm{GeV}^{-2}$.

In order to compare the H1 data to the fixed target data some of which which were fitted using two exponentials we present the average values of p_t^2 in figure 3. The averages are obtained over an interval $0 < p_t^2 < 1\,\mathrm{GeV}^2$ and are shown in figure 3 as a function of $W_{\gamma p}$. Within the experimental uncertainties both a Donnachie-Landshoff shrinkage and a flat dependence describe the data.

Elastic J/ψ production at High Q^2

The kinematic region covered by the new data is $2 < Q^2 < 8\,\mathrm{GeV}^2$ and $40 < W_{\gamma p} < 150\,\mathrm{GeV}$. The mass distribution of the selected events is shown in figure 4. The variables Q^2 and $W_{\gamma p}$ are reconstructed with the double angle method [1], using the scattering angle of the positron and the reconstructed angle of the J/ψ. The full systematic error of the cross section amounts to 19 %. The main contributions are the errors on the subtraction of the non-resonant and proton dissociation background (12 % and 8 % respectively).

The cross section as a function of $Q^2 + m_\psi^2$ is shown in two bins in figure 5 together with previous results at larger Q^2 [1]. A fit of the form $1/(Q^2 + m_\psi^2)^n$ to the HERA results yields $n = 2.1 \pm 0.3$ taking into account statistical and systematic errors added in quadrature. The result is compatible with our previous one and similar to results obtained for other vector mesons [1, 7].

Figure 2 shows the cross section as a function of $W_{\gamma p}$ at $Q^2 = 3.7\,\mathrm{GeV}^2$ together with previous results from H1, from the ZEUS collaboration [8] and from fixed target experiments[9]. Within errors the data at high Q^2 show a similar $W_{\gamma p}$ dependence as in photoproduction. The result of a fit $\propto W_{\gamma p}^{\delta}$ to all HERA data shown is:

$$\delta = 1.07 \pm 0.57 \quad \text{for} \quad Q^2 = 3.7\,\mathrm{GeV}^2$$

$$\delta = 1.22 \pm 0.52 \quad \text{for} \quad Q^2 = 16\,\mathrm{GeV}^2.$$

Conclusion

The elastic production of J/ψ mesons has been studied in an extended kinematic region. The cross section for photoproduction ($Q^2 \sim 0$) is observed to increase strongly with $W_{\gamma p}$ in the interval between 30 and 240 GeV. The data can be parameterized as $W_{\gamma p}^{\delta}$ with $\delta = 0.77 \pm 0.13$. The distribution of transverse momenta of the J/ψ was studied. The errors do not yet allow a conclusion concerning the existence of shrinkage or otherwise.

The analysis of the Q^2 dependence has been extended down to 2 GeV^2 in a range of $30 \leq W_{\gamma p} \leq 150\,\mathrm{GeV}$. A fit of the form $1/(Q^2 + m_{\psi}^2)^n$ to the results of H1 and ZEUS yields $n = 2.1 \pm 0.3$. The dependence of the γp cross section on $W_{\gamma p}$ for Q^2 values of 3.7 and 16 GeV^2 is compatible with the observation in photoproduction within errors.

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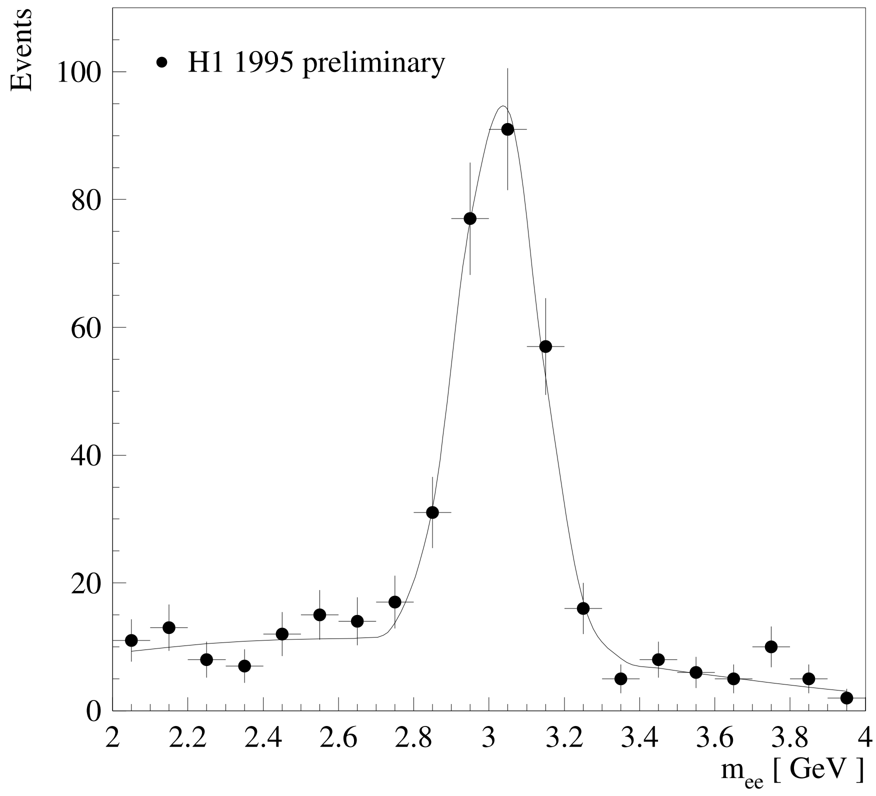

Figure 1: Mass distribution for e^+e^- pairs reconstructed from an electromagnetic shower in the SpaCal and a track ($120\,\mathrm{GeV} \leq W_{\gamma p} \leq 240\,\mathrm{GeV}$). The curve shows a fit to the data.

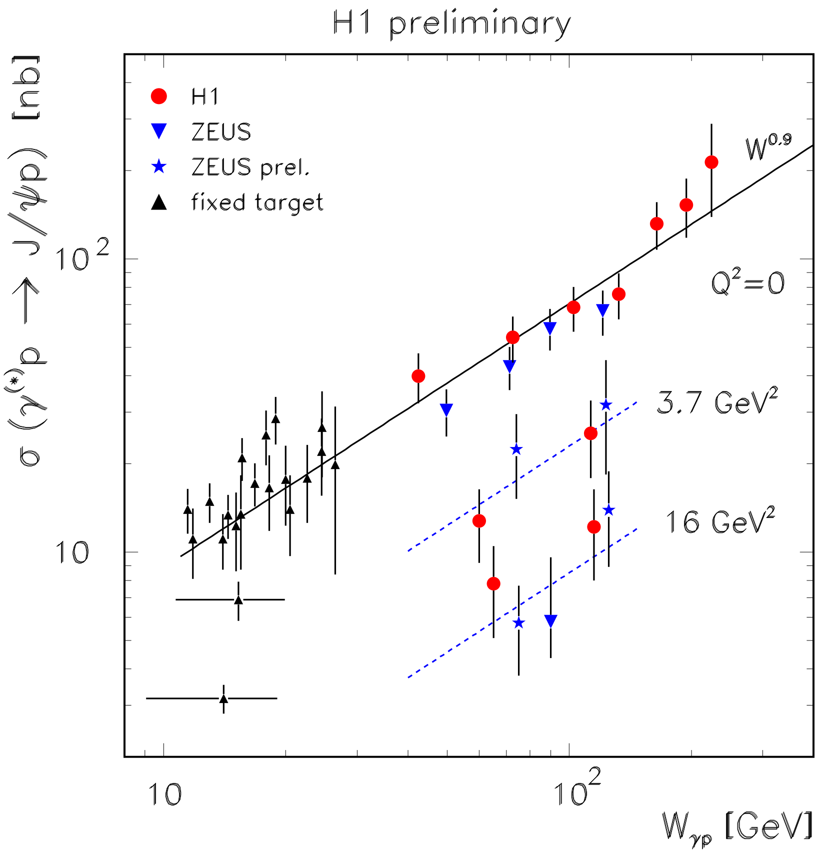

Figure 2: Elastic J/ψ production cross sections as a function of $W_{\gamma p}$. The error bars contain statistical and systematic errors added in quadrature. Lines $\propto W_{\gamma p}^{0.9}$ are drawn to guide the eye. (The new H1 points are at $W_{\gamma p} \geq 120\,\mathrm{GeV}$ for photoproduction and the points at Q^2=3.7 GeV^2; the other H1 points are from [1, 2]. The ZEUS photoproduction data are from [10], the data at high Q^2 from [8]. References for the fixed target data can be found in [1] .)

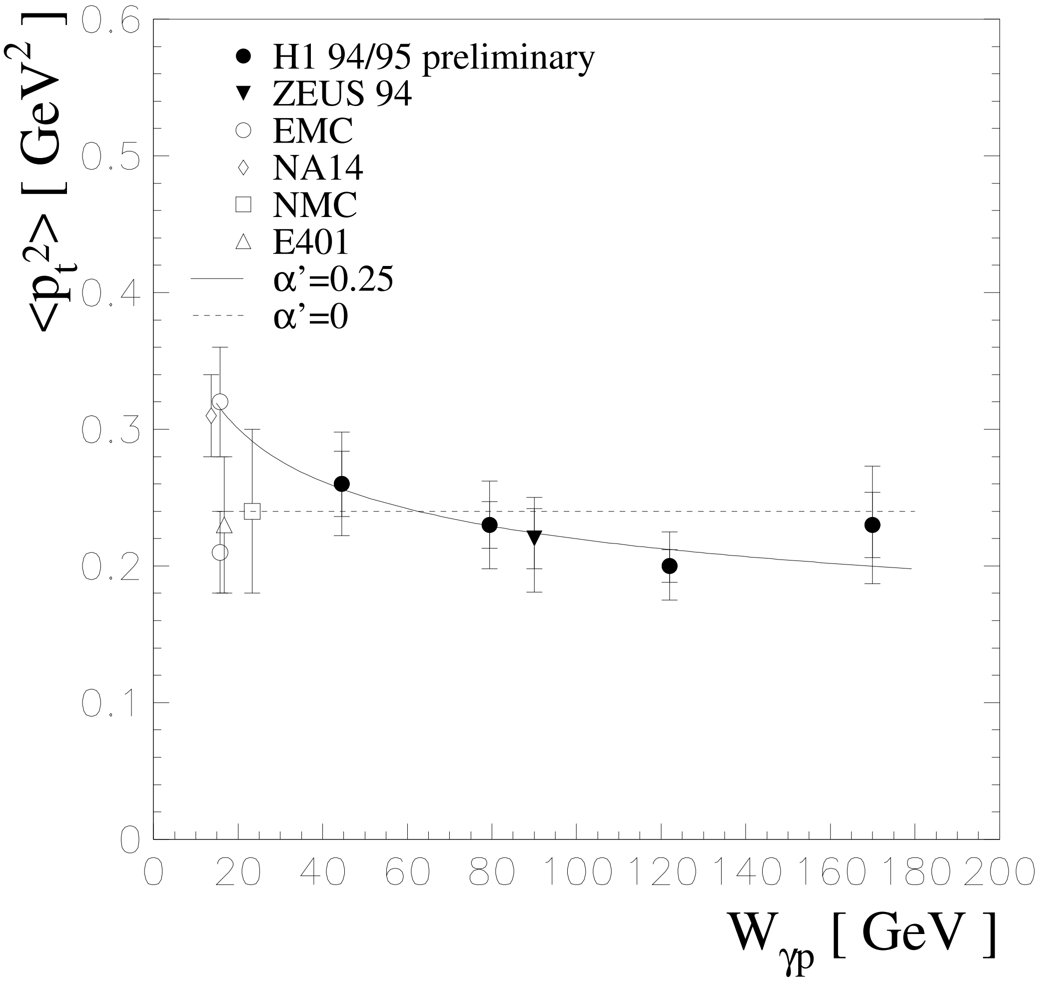

Figure 3: Average p_t^2 for $p_t^2 < 1\,\mathrm{GeV}^2$ compared to measurements of the ZEUS collaboration, to measurements at lower γp cm energies. The curves indicate the prediction of the Donnachie-Landshoff model with shrinkage and a flat $W_{\gamma p}$ dependence.

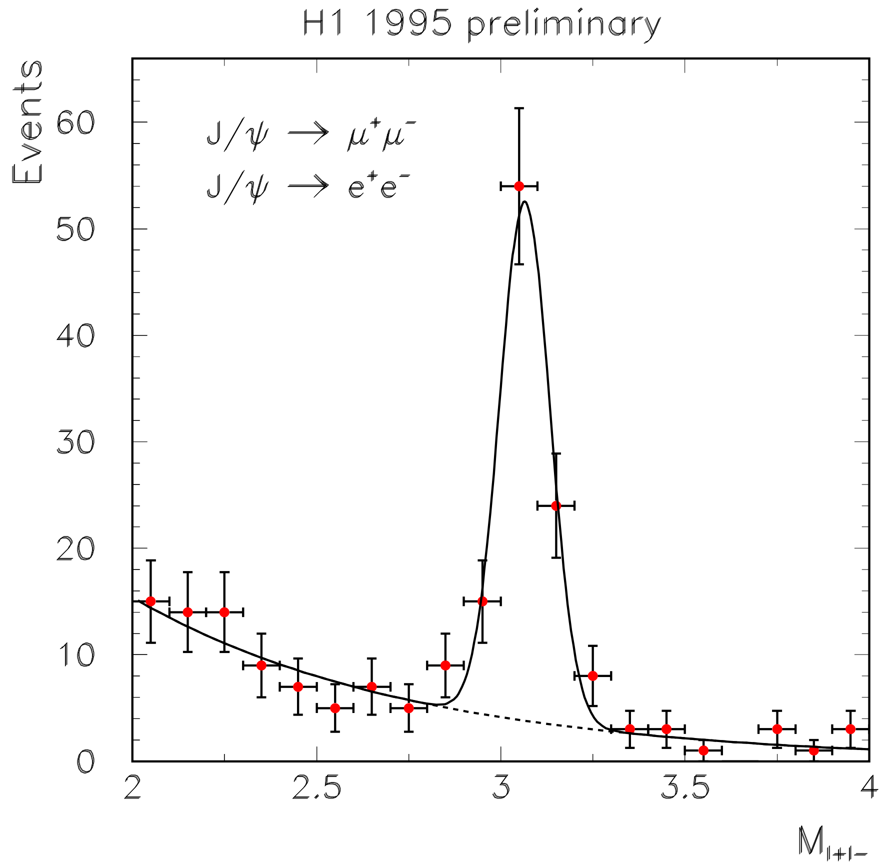

Figure 4: Mass distribution for $\mu^+\mu^-$ and e^+e^- pairs at $2 < Q^2 < 8\,\mathrm{GeV}^2$. The curve is a fit of a Gaussian plus an exponential background to the J/ψ mass region.

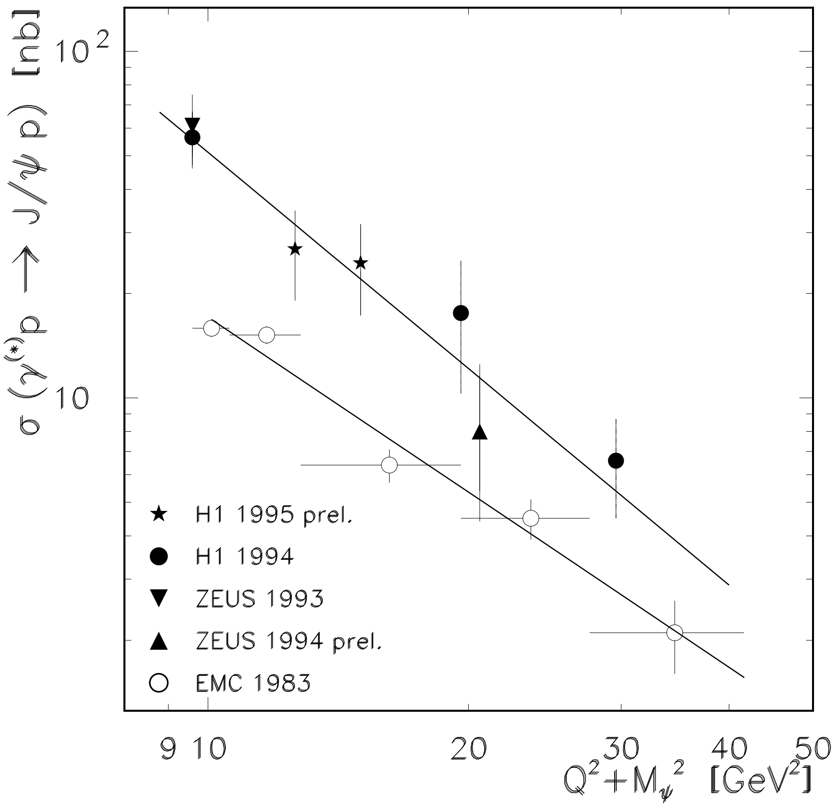

Figure 5: Virtual photon proton cross section for elastic J/ψ production as a function of $Q^2+m_\psi^2$. The error bars contain statistical and systematic errors added in quadrature. The lines are fits to the data of the form $(Q^2+m_\psi^2)^{-n}$.