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Inelastic Photoproduction of J/ψ and $\psi(2s)$ at H1

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Abstract

An updated measurement of the inelastic photoproduction of J/ψ mesons at photon proton center of mass energies $60 < W < 180$ GeV is presented. Data from 1996 and 1997 with an integrated luminosity of about a factor three more than previously are used. Cross sections as functions of W, $p_{t,\psi}^2$ and z are derived. QCD predictions are compared to the data. The production of $\psi(2s)$ mesons is analysed and the ratio of inelastic photoproduction of $\psi(2s)$ mesons over J/ψ mesons is determined.

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Introduction

The inelastic production of J/ψ mesons at HERA is dominated by photon gluon fusion. Calculations in the colour singlet model[1] are available in next to leading order (NLO) [2] and are found to describe the data well. In $p\overline{p}$ collisions at high energy deviations from the colour singlet model were found. So far the search for similar deviations at HERA was not successful within the available statistics. In this paper we present an updated measurement of inelastic production of J/ψ mesons with increased statistics.

The production of J/ψ mesons can proceed directly or via $\psi(2s)$ mesons which can decay into J/ψ mesons. The fraction of the latter contribution is predicted to be $\sim 15\%$ [2]. We present a measurement of the production rate of $\psi(2s)$ mesons relative to J/ψ in the inelastic regime.

Inelastic J/ψ Photoproduction

An updated measurement of the inelastic J/ψ photoproduction cross section via the decay $J/\psi \rightarrow \mu\mu$ is presented. Data from 1996 and 1997 with an integrated luminosity of $\mathcal{L} = 21.9$ pb^{-1} are used which is about three times the luminosity of the previous analysis [5]. The total photoproduction cross section is given as a function of W. Differential cross sections are extracted as functions of $p_{t,\psi}^2$ and z in an extended range, $0.3 < z < 0.9$. QCD predictions are compared to the data. The kinematic region covered is $Q^2 < 1$ GeV^2 and $60 < W < 180$ GeV.

J/ψ mesons are reconstructed via their leptonic decays into muons in the central tracking chambers of the H1 detector (polar angles $20 \leq \theta \leq 160°$). Both tracks have to be identified as muons, one in the muon detector, the other one in the calorimeter of the H1 detector or in the muon detector. Inelastic J/ψ events are selected by requiring in addition to the decay leptons at least one more particle from the interaction vertex. In addition the inelasticity z of the J/ψ meson is used. It is defined as $z = \frac{P_p \cdot P_\psi}{P_p \cdot q}$ where P_p, P_ψ and q are the four vectors of the proton, the J/ψ meson and the photon. To exclude diffractive events $z < 0.9$ is required. A cut $z > 0.3$ is applied to exclude regions with high background. This cut is however corrected for. For a comparison with theoretical predictions $z < 0.8$ and $p_{t,\psi}^2 > 1\ \mathrm{GeV}^2$ are required to avoid regions of soft gluon emission which are problematic in the calculations of NLO contributions.

Photoproduction events are selected by requiring no scattered positron to be visible in the calorimeter of the H1 detector. Rejecting energy clusters above 4 GeV restricts the photon virtuality to $Q^2 < 1\ \mathrm{GeV}^2$. In addition events with an identified positron in the electron tagger, $44m$ downstream the electron beam direction, are used. This gives a limit of $Q^2 < 0.01\ \mathrm{GeV}^2$. The number of J/ψ signal events is obtained for each analysis bin by fitting the sum of a Gaussian and a linear function to the mass spectrum of the unlike sign muon pairs. The peak position and the width of the Gaussian are determined by a fit to the complete data sample. The number of J/ψ mesons is calculated by counting the number of muon pairs in the mass window $2.9 < M_{\mu\mu} < 3.3$ GeV and subtracting the non–resonant background obtained from the linear fit.

The calculation of the cross section proceeds as in [6]: after correcting the observed number of events for acceptance and efficiencies, the ep cross section is obtained. It is converted into a γp cross section assuming factorisation of the ep reaction into emission of photons described by a photon flux and the γp interaction.

All efficiencies are taken from a Monte Carlo simulation (EPJPSI) [3] after reweighting the $p_{t,\psi}^2$ distribution according to an exponential which was determined from the data for $p_{t,\psi}^2 > 1\ \mathrm{GeV}^2$. The efficiency of the lepton identification and of the trigger was checked and adjusted with data using independent subtriggers. The remaining differences between data and MC are used as systematic errors (table 1).
Background from resolved photon processes (which are more important than in the previous analysis because of the lower z cut) is estimated to be $\sim 14\%$ in the lowest z bin and $\sim 3.5\%$ in the second z bin (assuming the colour singlet model [1] and GRV-G LO [4] as photon parton density) and is **not** subtracted, but included in the systematic error. For $z > 0.6$ the background was found to be negligible.
Background from diffractive processes with proton dissociation and from decays of B mesons is estimated to be below 3%. No correction is applied, however the number is included in the systematic error.
For the total cross section and the differential cross section as a function of $p_{t,\psi}^2$ an extrapolation to the full range $0 < z < 0.9$ assuming photon gluon fusion is done. The corrections amounts to 6% and is included in the systematic error.
To study the systematic uncertainties the cut demanding at least 1 additional tracks was replaced by a cut on the energy in the forward part of the LAr calorimeter ($< 35^\circ$) at 2 or 5 GeV. No significant change in the cross sections was observed.

source	amount
track reconstruction	2.5%
lepton identification	10%
trigger efficiency	16%
resolved photon background	$0 - 14\%$
proton dissociation & B decays	3%
extrapolation in z	6%
luminosity	1.6%
branching ratio	3.2%
photon flux	4%
sum	$21 - 25\%$

Table 1: Sources of the systematic error. The error for resolved photon contributions contributes only below $z < 0.6$.

The cross section for inelastic events with $z < 0.9$ as function of W is shown in fig. 1 a), for $z < 0.8$ and transverse momentum $p_{t,\psi}^2 > 1\ \mathrm{GeV}^2$ of the J/ψ meson in fig. 1 b). The data points marked "low Q^2 " were obtained by reconstructing the scattered electron at small scattering angles. They correspond to $Q^2 < 0.01\ \mathrm{GeV}^2$. In addition results from a previous H1 analysis [5]

are shown. The data agree well with the previous analysis. NLO QCD calculations [2] using a charm mass of $m_c = 1.4$ GeV and $\Lambda_{\overline{MS}} = 300$ MeV are compared to the data. Good agreement in shape between data and QCD predictions is found for both distributions. By avoiding theoretical problems in the low $p_{t,\psi}^2$ region in b) the absolute normalisation of the data is reproduced. The differential cross sections $d\sigma/dp_{t,\psi}^2$ (fig. 1 c)) and $d\sigma/dz$ (fig. 1 d)) are within errors well described by NLO QCD calculations in the colour singlet model.
There is no evidence for large colour octet contributions to the cross section in the region $z > 0.75$ as inferred in [7] using the colour octet matrix elements fitted to $p\overline{p}$ data.

Inelastic $\psi(2s)$ Production

Data taken in 1997 with the H1 detector amounting to an integrated luminosity of 15.4 pb^{-1} are used. J/ψ mesons and $\psi(2s)$ mesons are detected via their decay to muon pairs. The same selection criteria are used for both channels, so that most errors cancel in the measured ratio. Photoproduction is selected by requiring no scattered positron to be measured in the detector, which corresponds to $Q^2 < 1$ GeV^2. The photon proton center of mass energy is restricted to $40 < W < 180$ GeV. An inclusive selection including the full z-range is carried out. The inelastic samples are defined by a cut $z < 0.9$. The diffractive region $z > 0.9$ is used for cross checks. The ratio of production rates of $\psi(2s)$ mesons in this range was found to agree well with previous results [8]. In fig. 2 the signals are shown for the full data set and for the inelastic regions used to extract the number of events.

Efficiencies and acceptance are extracted using an inelastic Monte Carlo simulation (EPJPSI)[3] and a diffractive one (DIFFVM) including proton dissociative and elastic processes. The fractions are determined by normalizing the simulated events from EPJPSI to the selected J/ψ data in the region $z < 0.9$ and adding events from DIFFVM to describe the data at $z > 0.9$. The normalisation factors thus obtained are then taken over for the $\psi(2s)$ meson.

The ratio $\frac{\psi(2s)}{J/\psi_{all}}$ is extracted using the number of events, the selection and trigger efficiencies and the branching ratios. The average value of the photon proton center of mass energy differs slightly for the J/ψ (100 GeV) and the $\psi(2s)$ sample (121 GeV) and is corrected for by assuming the measured W dependence of the J/ψ cross section.

$$\frac{\psi(2s)}{J/\psi_{all}} = \frac{N_{\psi(2s)}}{N_{J/\psi}} \cdot \frac{\epsilon_{J/\psi} Br_{J/\psi}}{\epsilon_{\psi(2s)} Br_{\psi(2s)}} \cdot \left(\frac{W_{J/\psi}}{W_{\psi(2s)}}\right)^{\delta}$$

Using $Br_{\psi(2s)} = (0.84 \pm 0.06)\%$[1] and $\delta = 0.9 \pm 0.26$ one obtains:

$$\frac{\psi(2s)}{J/\psi_{all}} = 0.210 \pm 0.048 \text{ (stat) } \pm 0.032 \text{ (sys)}\,.$$

The systematic uncertainties contain contributions from the uncertainties of the branching ratios and from the Monte Carlo description of the data.

[1]Due to the large error on the measured branching ratio $Br_{\psi(2s)\to\mu\mu} = (0.77 \pm 0.17)\%$ compared to the branching ratio $Br_{\psi(2s)\to ee} = (0.85 \pm 0.07)\%$ lepton universality is assumed and an averaged branching ratio is used.

The measured number of J/ψ mesons contains a directly produced contribution and a contribution from $\psi(2s)$ which can decay to J/ψ either directly or via χ states:

$$J/\psi_{all} = J/\psi_{direct} + J/\psi_{cascade}$$

The fraction of J/ψ from $\psi(2s)$ (including decays via χ states) is $k = 0.5769 \pm 0.0301$[9]. Using this number the ratio of $\psi(2s)$ over directly produced J/ψs can be calculated and the ratio of the "cascade" contribution to direct J/ψ production.

$$\begin{aligned} \frac{\psi(2s)}{J/\psi_{direct}} &= 0.24 \pm 0.08 \\ \frac{J/\psi_{cascade}}{J/\psi_{direct}} &= 0.14 \pm 0.05 \end{aligned}$$

The errors contain statistical and systematic errors added in quadrature.

Conclusion

Using increased statistics the cross sections for inelastic production of J/ψ mesons confirm previous findings in an extended kinematical range: The dependence on W, $p_{t,\psi}^2$ and z is well described by the colour singlet model in NLO.
The ratio of $\psi(2s)$ mesons to J/ψ mesons is measured to be 0.21 ± 0.06, where the error contains statistical and systematic uncertainties. Using the nominal values for the cascade decays of $\psi(2s)$ to J/ψ a ratio of J/ψ via $\psi(2s)$ to directly produced J/ψ is derived as 0.14 ± 0.05 which is in agreement with theoretical predictions.

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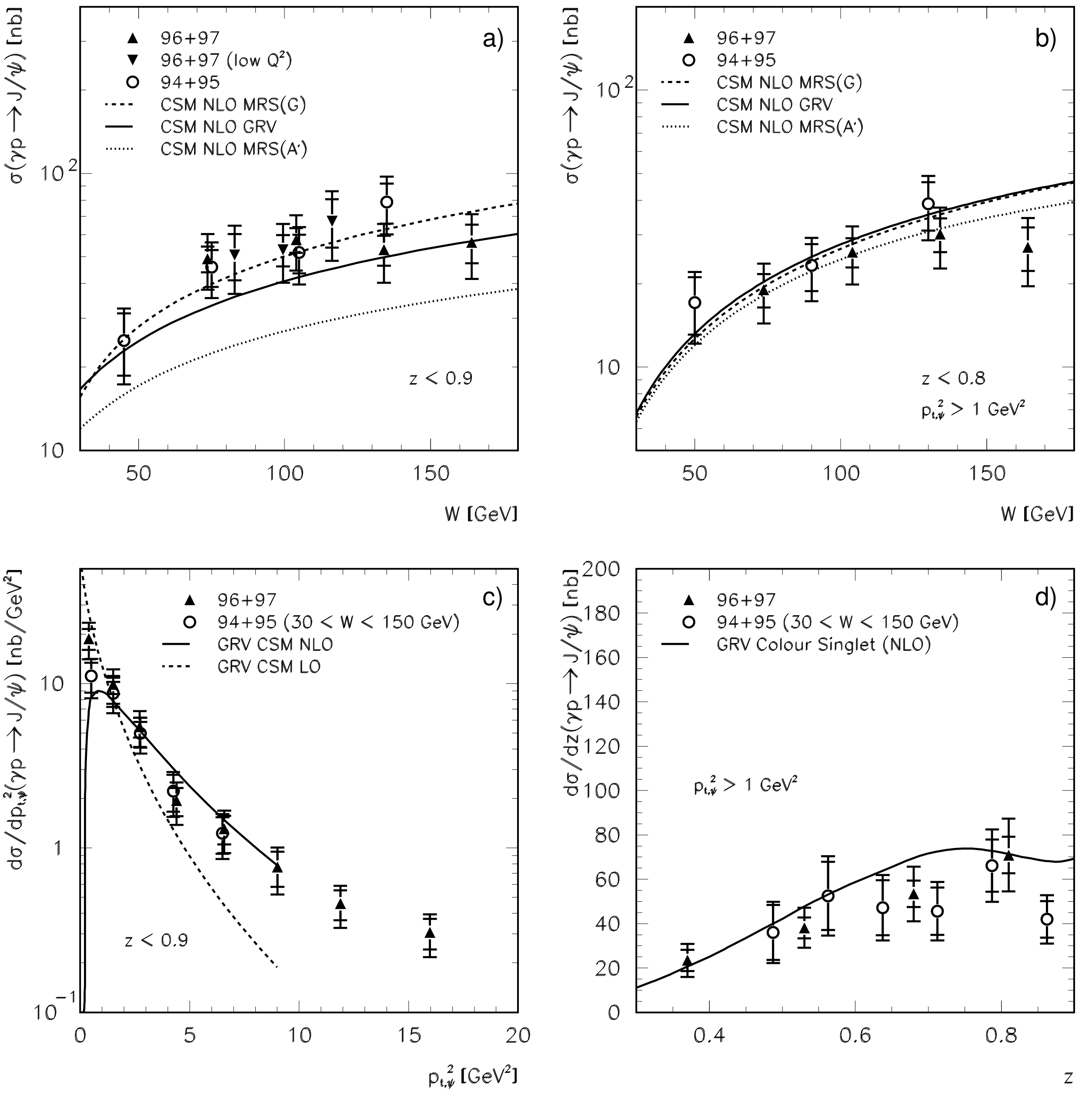

Figure 1: a) Total photoproduction cross section for inelastic J/ψ production for $z < 0.9$ and b) for $z < 0.8$ and $p_{t,\psi}^2 > 1\ \mathrm{GeV}^2$. The inner error bars are statistical, the outer include statistical and systematic uncertainties added in quadrature. The curves represent NLO calculations [2] for different gluon distributions and contain a 15% contribution of $\psi(2s)$ background. c) Differential cross section $d\sigma_{\gamma p}/dp_{t,\psi}^2$ with $z < 0.9$ integrated over $60 < W < 180$ GeV. The full line is a NLO calculation [2] at $W = 100$ GeV with the GRV structure function, the dashed line a LO calculation. d) $d\sigma_{\gamma p}/dz$ with a cut $p_{t,\psi}^2 > 1\ \mathrm{GeV}^2$, in comparison with a NLO calculation in the colour singlet model with the GRV structure function.

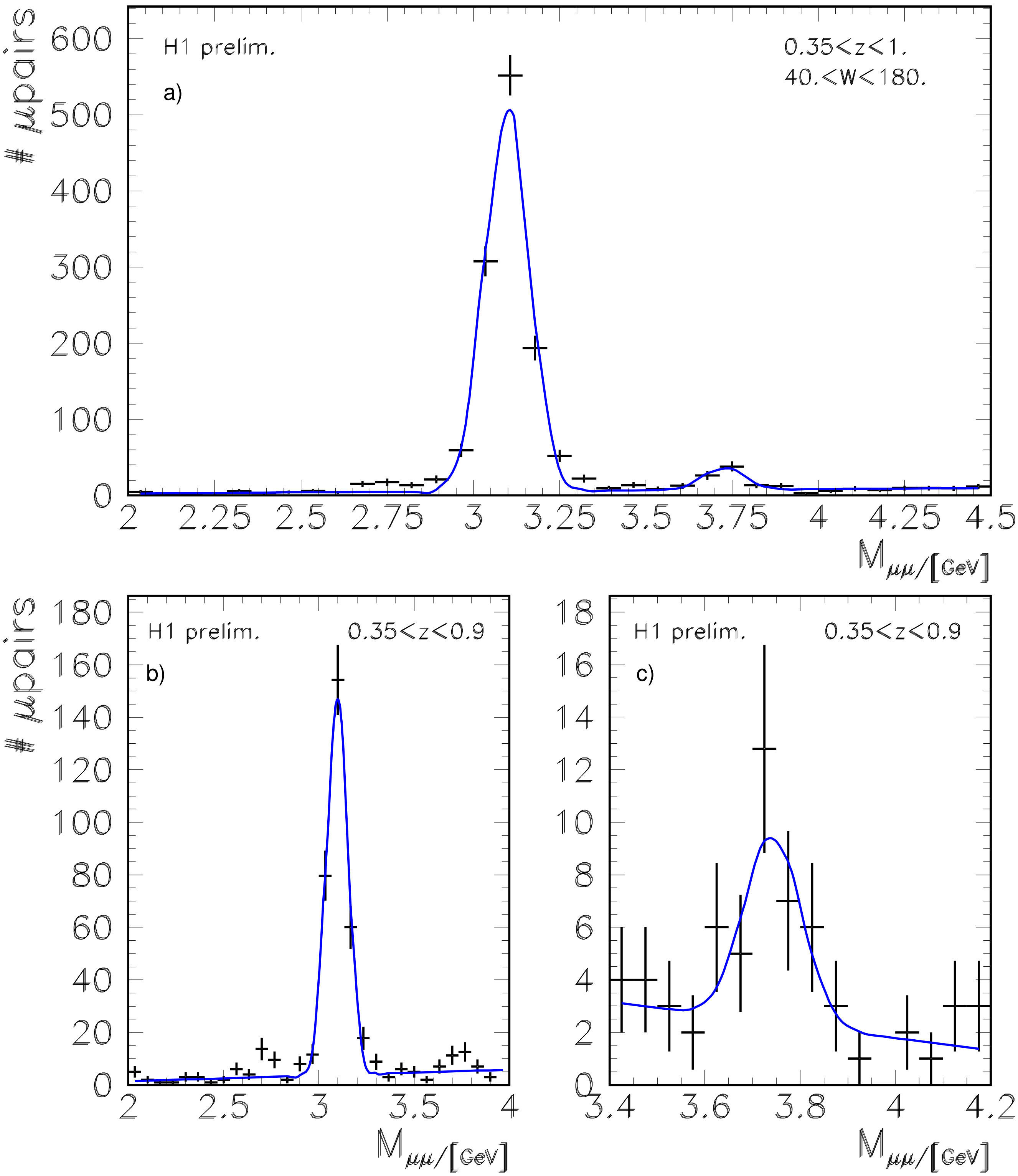

Figure 2: Invariant mass distributions of the unlike sign dimuon pairs; a) the complete sample, $0.35 < z < 1$; b) the inelastic J/ψ sample; c) the inelastic $\psi(2s)$ sample.