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Diffractive and Non-Diffractive Photoproduction of J/ψ at H1

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Abstract

Elastic photoproduction of J/ψ mesons has been measured in the H1 detector at HERA with increased statistics and in an extended range of the photon proton cms energy $30 \leq W \leq 260\,\mathrm{GeV}$. The cross-section is found to increase steeply in this range, approximately as $W^{0.6}$. It is well described by a QCD based model using a gluon structure function increasing towards low x. The precision of the cross-section measurement for inelastic J/ψ meson production has been increased by doubling statistics. A good description of the data is achieved by boson gluon fusion in the coulor singlet model in NLO.

Introduction

Previous H1 data [10] about photoproduction of J/ψ (that is $ep \to e\, J/\psi\, X$ at $Q^2 \sim 0$) from the analysis of an integrated luminosity of approximately 2.7 pb^{-1} have shown the following results:

The **elastic** process ($X = p$) showed features of a diffractive process, such as an exponential t distribution at low t and a transverse polarisation of the J/ψ in agreement with s-channel helicity conservation. However the dependence of the cross section on the γp cm energy W was found to be much steeper than predicted in diffractive models, e.g. by Donnachie and Landshoff [2]. A QCD based model which relates elastic J/ψ production to the square of the gluon distribution in the proton was found to be more successful in the description of the data [3]. If this model is confirmed the process is a sensitive probe of the gluon distribution in the proton, since it enters quadratically. Recently contributions of higher order have been calculated in this model [5].

Inelastic photoproduction of J/ψ mesons can proceed via the photon gluon fusion mechanism and has been proposed to determine the gluon density in the proton since a long time. Inelastic J/ψ mesons were reconstructed and were found to be well described by the colour singlet model in NLO [6, 7] in a restricted kinematical range. These restrictions in the inelasticity and the transverse momentum of the J/ψ avoid singular regions in the calculations. Unfortunately they also severely limit available statistics.

We report here on updates of the previous analysis with increased statistics and on a new analysis extending the range of cms energy covered previously. The data were taken in 1994 and 1995 with the H1 detector [8] operating at the lepton proton storage ring HERA, where positrons of 27.5 GeV collide with protons of 820 GeV.

New results on ψ' are reported in a separate paper [1].

Elastic Photoproduction of J/ψ

Elastic J/ψ events are reconstructed via their leptonic decays into e^+e^- or $\mu^+\mu^-$. Two separate event selections have been carried out, which cover two different ranges of W. Both select the decay leptons in the main H1 detector ($4 < \theta < 174°$) and require them to be the only particles from the interaction point. In addition, counters covering polar angles close to the proton beam $0.06 < \theta < 0.26°$ and $3 < \theta < 17°$) – the so-called "forward counters" – are utilized to remove background from events with proton dissociation.

The high W Selection (new)

The range in W over which measurements of elastic J/ψ production have been made previously has been substantially increased by utilisation of the backward electromagnetic calorimeter (BEMC). This device is used to trigger, identify and reconstruct electrons or positrons from the decay $J/\psi \to e^+e^-$. Its angular range ($155° < \theta < 174°$) allows electrons to be detected at larger polar angles than analyses that use only the tracking detectors and thus enables the high W region to be explored.

The data for these measurements were taken in the 1994 data taking period and amount to a total integrated luminosity of 2.4 pb^{-1}. The events were triggered with the requirement of an energy deposit in the BEMC, for which the trigger efficiency approaches

100% for energies greater than 8 GeV. Elastic photoproduction J/ψ candidates were selected by requiring, in addition to a BEMC energy cluster with $E > 8$ GeV, exactly one track in the central tracker with $\theta < 160°$ OR a second BEMC cluster with energy above 1 GeV. Events with additional tracks or unassociated energy in the calorimeters above noise thresholds were rejected. In order to suppress events with photons or hadrons each BEMC energy cluster was required to have a lateral size of less than 5 cm and to have an associated hit in the backward proportional chamber (BPC) within 5 cm. This hit was also used to improve the angular measurement of the electron candidate. No lepton identification of the single track was required. Much of the remaining background, mainly from diffractive photoproduction and events at high Q^2 in which one or both of the leptons were misidentified, was vetoed by requiring the total photon proton cms energy to be within $170 < W < 260$ GeV, the total observed transverse momentum $p_t^2 < 1$ GeV^2 and $2.4 < M_{ee} < 3.8$ GeV. J/ψ production in which the proton dissociated rather than remained intact were rejected by requiring no activity in the forward counters.

The event sample was divided into two bins in W with central values 185 GeV and 230 GeV, corresponding to the two cases of events with and without a central track respectively. The invariant mass spectra for the two W bins are shown in figure 1.

The Selection at $30 \leq W \leq 150$ GeV (update)

The number of J/ψs in the range $30 \leq W \leq 150$ GeV has been approximately doubled by doubling the integrated luminosity, in 1994 data from ~ 2.7 pb^{-1} were analysed, in 1995 data from ~ 3.9 pb^{-1} were added. J/ψ mesons are reconstructed via their leptonic decays into electrons and muons in the central tracking chambers of the H1 detector (polar angles $20 \leq \theta \leq 160°$). Both leptons are identified and required to be the only particles coming from the interaction vertex. The contribution from events with proton dissociation is subtracted using the forward detectors.

Calculation of the Cross Section and Results

The calculation of the cross section proceeds as in [10]: efficiencies and acceptance as well as the remaining background from proton dissociation is corrected for using a Monte Carlo simulation of diffractive J/ψ production with and without proton dissociation which has been tuned to the data [4]. After taking into account the leptonic branching ratio, a correction for contamination with ψ' decays, and the luminosity an ep cross section is calculated in bins of W for $Q^2 < 1(4)$ GeV. This is then converted into a γp cross section assuming factorisation of the ep reaction into emission of a photon followed by a γp interaction.

The elastic cross section for J/ψ meson production as a function of $W_{\gamma p}$ is shown in figure 3. A fit of the form W^δ to the H1 data between $30 \leq W \leq 260$ GeV yields a value of $\delta = 0.52 \pm 0.13$. Including the points from ZEUS [9] leads to a value of $\delta = 0.60 \pm 0.12$. The prediction of the Donnachie-Landshoff model (long dashed line, $\delta = 0.32$) does not describe the HERA data. A better description is given by the pQCD calculations of the Ryskin model using the gluon parametrisation MRS(A') (short dashed line).

The distribution of the momentum transfer t ($t \approx -p_t^2$) in the range $30 \leq W \leq 150$ GeV can be fit by an exponential $exp(-b|t|)$ for values of $p_t^2 < 1$ GeV^2. A χ^2 fit yields

$b = (4.1 \pm 0.2 \pm 0.2)\,\mathrm{GeV}^{-2}$ (fig. 4). Subdividing the data in a low and a high W range, $W < 90\,\mathrm{GeV}$ and $90 < W < 150\,\mathrm{GeV}$, yields b–values of $b = (3.7 \pm 0.2 \pm 0.2)\,\mathrm{GeV}^{-2}$ and $b = (4.6 \pm 0.3 \pm 0.3)\,\mathrm{GeV}^{-2}$. The difference between the two values is 0.9 ± 0.5 GeV^{-2}, 1.5 standard deviations from 0. Assuming a slope of the Pomeron trajectory of 0.5 GeV^{-2} predicts a differenc of 0.5 GeV^{-2} between the two values.

Inelastic J/ψ Photoproduction(update)

Inelastic J/ψ events are selected by requiring in addition to the decay leptons at least one more particle from the beam interaction vertex. In addition the inelasticity z of the J/ψ meson is used, which 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. A cut $z > 0.45$ is applied to exclude contributions from resolved events, this cut is however corrected for. $z < 0.8$ and $p_t^2 > 1$ GeV^2 are required to avoid regions of soft gluon emission which are problematic in the calculations of NLO contributions. The cross section for inelastic events with $z < 0.8$ and transverse momentum $p_t^2 > 1$ GeV^2 of the J/ψ meson as function of W is shown in fig. 5. The data points are compared to NLO QCD calculations [7] using a charm mass of $m_c = 1.4\,\mathrm{GeV}$ and $\Lambda_{\overline{MS}} = 300\,\mathrm{MeV}$. Agreement in shape and absolute normalisation between data and QCD predictions is found.

The differential cross section $d\sigma/dz$ is well described by QCD calculations in colour singlet model (fig. 6). There is no evidence for large colour octet contributions to the cross section in the region $z > 0.75$ as inferred [14] if the colour octet matrix elements fitted to tevatron data.

Summary

Elastic J/ψ production has been measured with improved statistics and the W range was extended to $W = 260\,\mathrm{GeV}$. The steep increase of the total photon proton cross section with energy is now observed in the HERA energy range alone. Inelastic J/ψ production has been measured with improved precision. The data are well described by the colour singlet model for inelasticity $z < 0.8$ and $p_t^2 > 1$ GeV^2.

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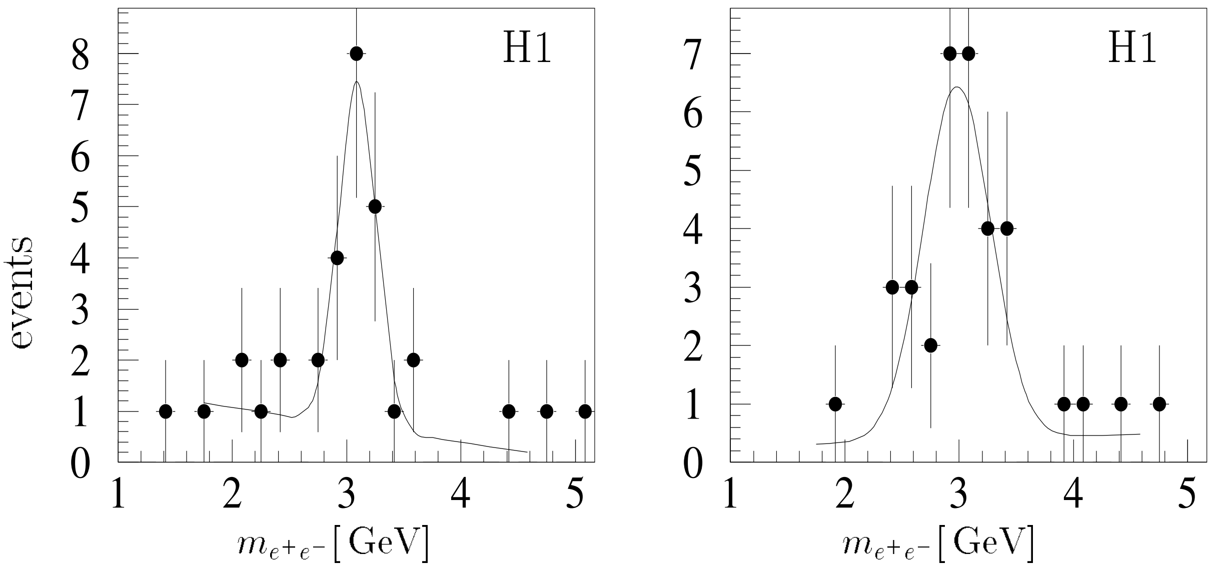

Figure 1: *Mass distribution for elastic e^+e^-pairs reconstructed from an electromagnetic shower and a track ($170 \leq W \leq 200\,GeV$, left) and from two electromagnetic showers in the backward electromagnetic calorimeter (BEMC) of the H1 detecto ($200 \leq W \leq 260\,GeV$, right). The curves are fits of a Gaussian plus background to the J/ψ mass region.*

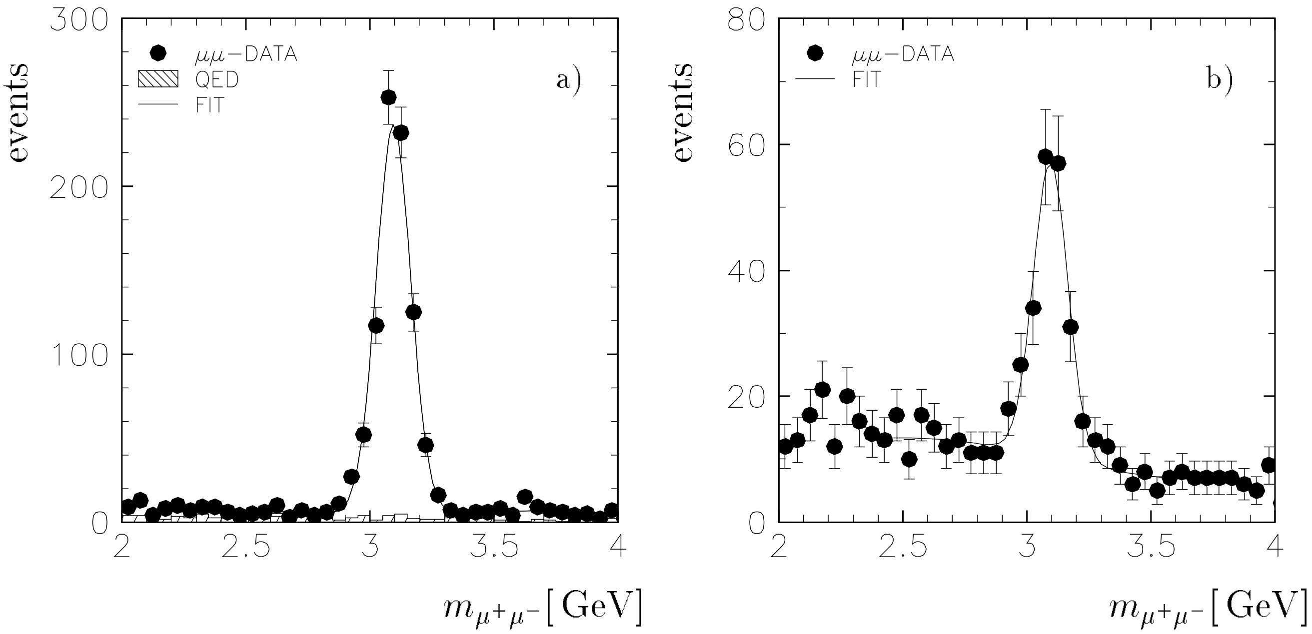

Figure 2: *Mass distribution for $\mu^+\mu^-$ pairs ($30 \leq W \leq 150\,GeV$) (a) from the elastic selection and (b) for the inelastic selection. The curves are fits of a Gaussian plus a polynomial background to the J/ψ mass region.*

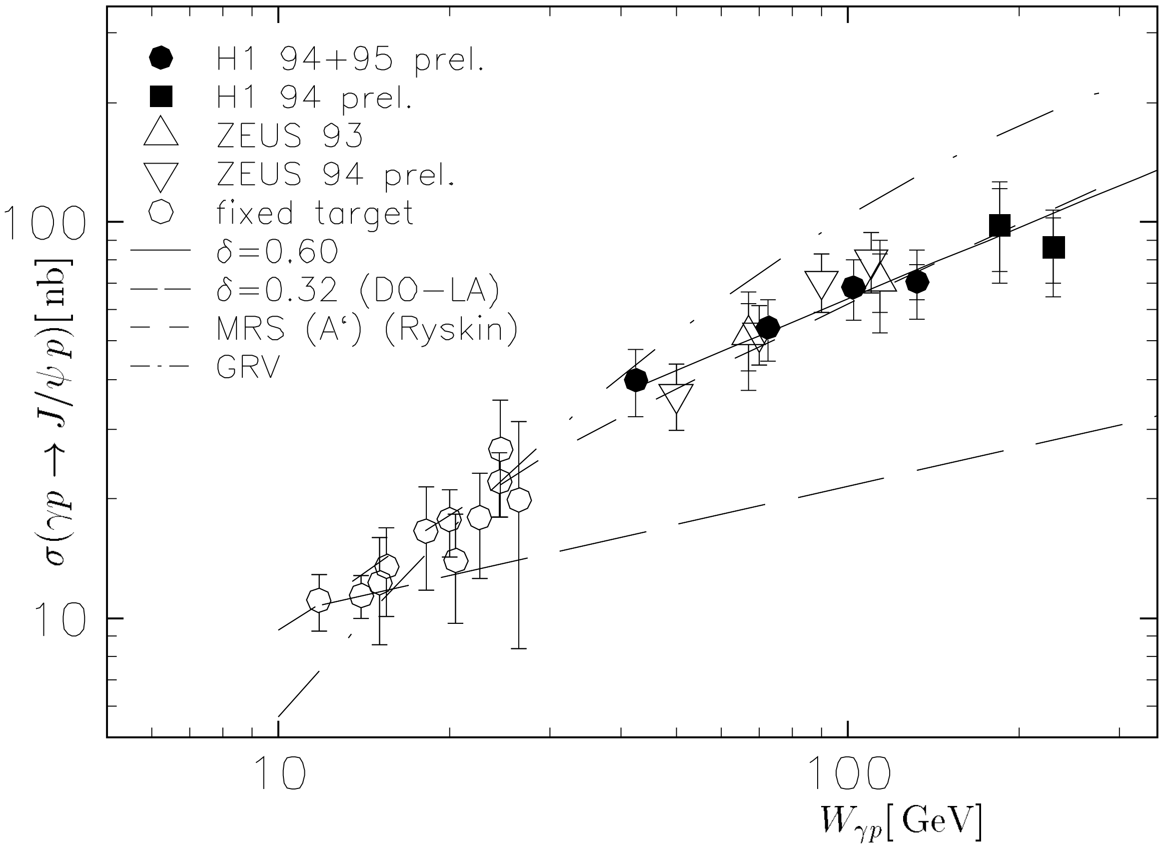

Figure 3: *Total cross section for* **elastic** J/ψ *photoproduction. The inner error bars of the HERA points are statistical, the outer ones contain statistical and systematic errors added in quadrature. The data at lower cms energies are from previous experiments [11, 12, 13]. A parametrisation of the energy dependence as* $W_{\gamma p}^{\delta}$ *with* $\delta = 0.60$ *(full curve) fitted to all HERA data and* $\delta = 0.32$ *(long dashed) normalized to the E 516 point is shown. Also shown is the result of calculations according to the Ryskin model [5] using the MRSA' (dashed) and GRV parametrisations (dash dotted) of the gluon density.*

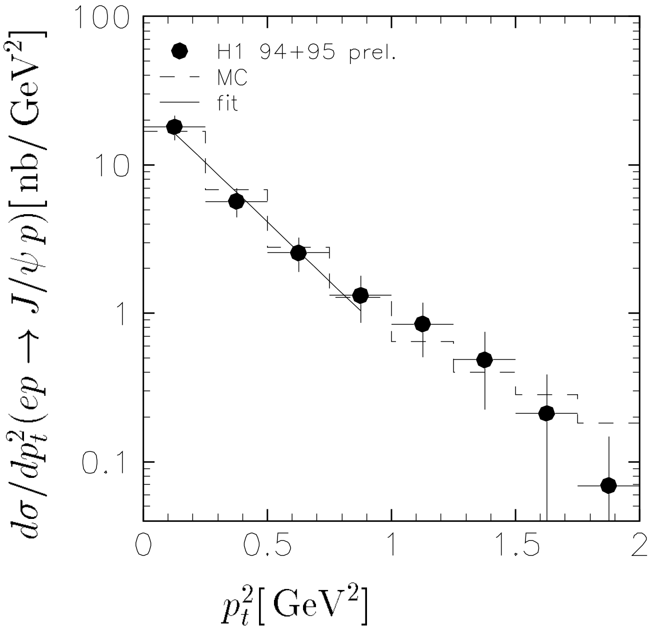

Figure 4: p_t^2 *distribution of elastic* J/ψ *events for* $30 \leq W \leq 150\,GeV$). *The fit of an exponential to the data with* $b = 4.1\ GeV^{-2}$ *is shown.*

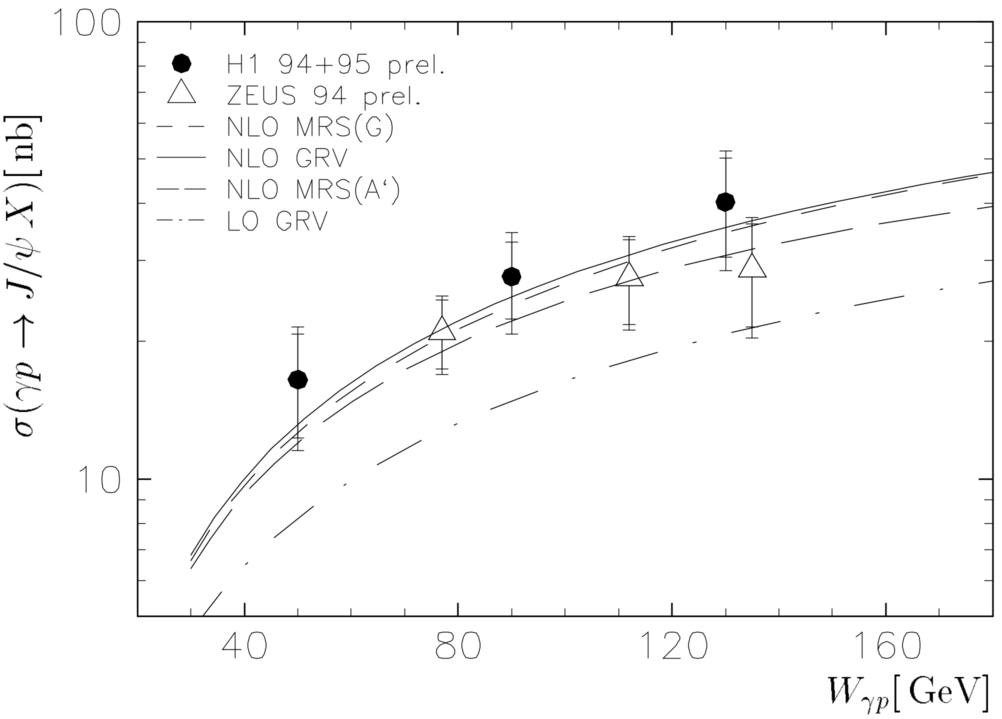

Figure 5: *Total cross section for* **inelastic** J/ψ*-production for* $z < 0.8$ *and* $p_t^2 > 1$ GeV^2. *The inner error bars of the H1 points are statistical, the outer include statistical and systematic errors added in quadrature. The curves represent NLO calculations [7] for different gluon distributions and contain a 15% contribution of* ψ' *background.*

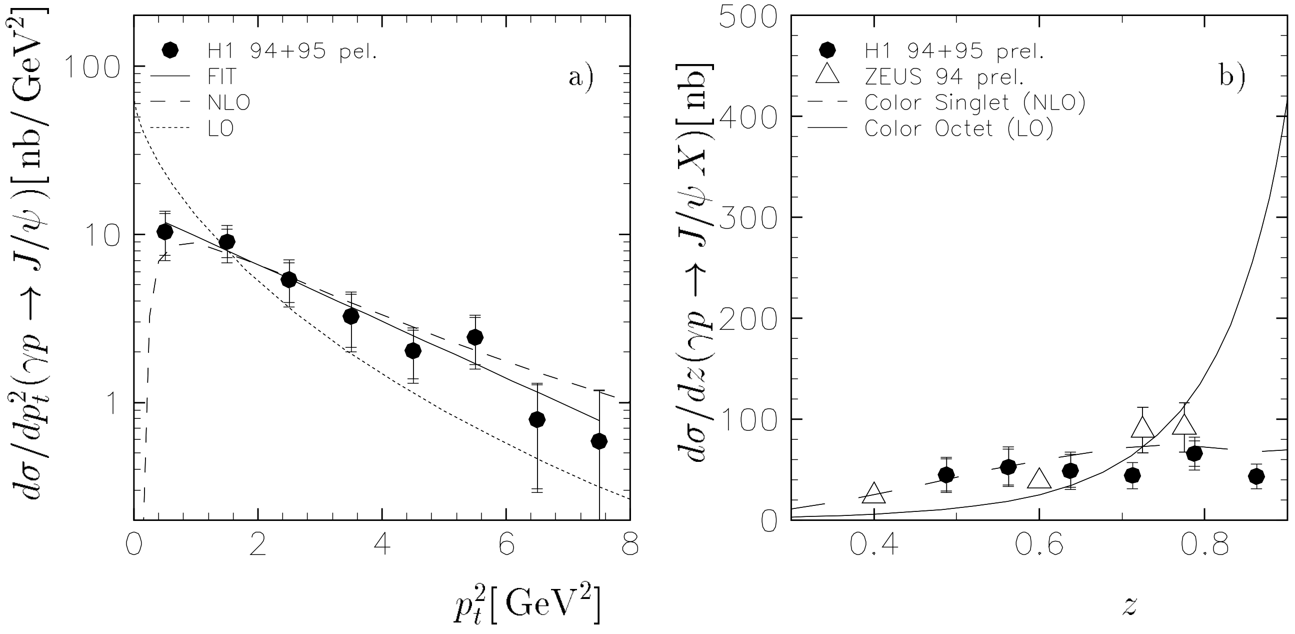

Figure 6: a) $d\sigma_{\gamma p}/dp_t^2$ *for* **inelastic** J/ψ *production with* $z < 0.9$ *integrated over 30 GeV* $\leq W_{\gamma p} \leq 150$ GeV. *The straight line is an exponential fit to the data in the range* $p_t^2 \leq 8$ GeV^2, *the dashed line is a NLO calculation [7] at* $W_{\gamma p} = 100$ *GeV with the GRV structure function. b)* $d\sigma_{\gamma p}/dz$ *for inelastic* J/ψ *production with a cut* $p_t^2 \geq 1$ GeV^2, *in comparison with NLO calculations in the colour singlet model with the GRV structure function. The LO colour octet calculation is from [14].*