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Measurement of the $\psi(2S)$ and J/ψ cross section ratio in photoproduction with the ZEUS detector at HERA

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The exclusive photoproduction reaction $\gamma p \to \psi(2S)p$ has been studied with the ZEUS detector in ep collisions at HERA using an integrated luminosity of 333 pb^{-1}, in the kinematic range $30 < W < 180$ GeV, $Q^2 < 1$ GeV^2, $|t| < 5$ GeV^2, where W is the photon proton centre-of-mass energy, Q^2 - the photon virtuality and t - four-momentum transfer at the proton vertex. The $\psi(2S)$ mesons were identified via the decay channels: $\psi(2S) \to \mu^+\mu^-$ and $J/\psi\pi^+\pi^-$ with $J/\psi \to \mu^+\mu^-$. The ratio of the production cross sections $R = \sigma(\psi(2S))/\sigma(J/\psi)$ was measured as a function of W, for three W intervals: $30 < W < 80$ GeV, $80 < W < 130$ GeV and $130 < W < 180$ GeV and in the whole kinematic range accessible in this analysis. The advantage of including the 4-prong final state channel is its negligible background in the respective invariant mass distribution and small systematic uncertainty due to the branching ratio (BR) comparing to the BR of direct decay of $\psi(2S)$ into a muon pair.
The presented analysis is complementary to already published ZEUS measurement of the same quantity as a function of Q^2 in deep-inelastic (DIS) channel [1].

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Exclusive heavy vector meson production in ep collisions

The exclusive photo- and electro-production of light and heavy vector mesons has been extensively studied at HERA. Exclusive photoproduction of heavy vector mesons, like J/ψ, $\psi(2S)$ and Υ, can be described by models based on perturbative QCD (pQCD) since the large masses of the charm and the bottom quarks provide the hard scale. In such models the process is assumed to proceed in three steps as shown in Figure 2: the photon fluctuates into a corresponding $q\bar{q}$ pair of small transverse size which subsequently, in the lowest order, interacts with the proton via the exchange of a pair of gluons in a color-singlet state forming a heavy vector meson. The cross section for this process is thus proportional to the square of the gluon density in the proton.

An important source of background is due the diffractive reaction $ep \to \psi(2S)Y$, in which the proton dissociates into a hadronic state Y, which is described by M_Y, being the invariant mass of the diffractively produced hadronic state Y.

Results

Exclusive $\psi(2S)$ and J/ψ events were selected using dedicated triggers and software selections. For 2- and 4-prong decay channels at the trigger level the selection was driven by muons by requiring at least one track in the Central Tracker associated with a Forward, Barrel, Rear Muon Chambers deposit or with a signal in the Backing Calorimeter consistent with a muon. Figure 1 presents an example of di-muon invariant mass distribution obtained for three W bins investigated. The present data sample corresponds to 333 pb^{-1} collected during the HERA-II data taking period (2003-2007) in e^-p and e^+p beam configurations.

In this paper, a measurement of the ratio of the cross sections of the reactions $\gamma p \to \psi(2S) + p$ and $\gamma p \to J/\psi(1S) + p$ is presented. The $\psi(2S)$ and the $J/\psi(1S)$ have the same quark content but different radial distributions of the wave functions, and their mass difference is small compared to the HERA centre-of-mass energy. Therefore, this measurement allows QCD predictions of the wave function dependence of the $c\bar{c}$–proton cross section to be tested. A suppression of the $\psi(2S)$ cross section relative to the $J/\psi(1S)$ is expected and observed (Figure 3), as the $\psi(2S)$ wave function has a radial node close to the typical transverse separation of the virtual $c\bar{c}$ pair.

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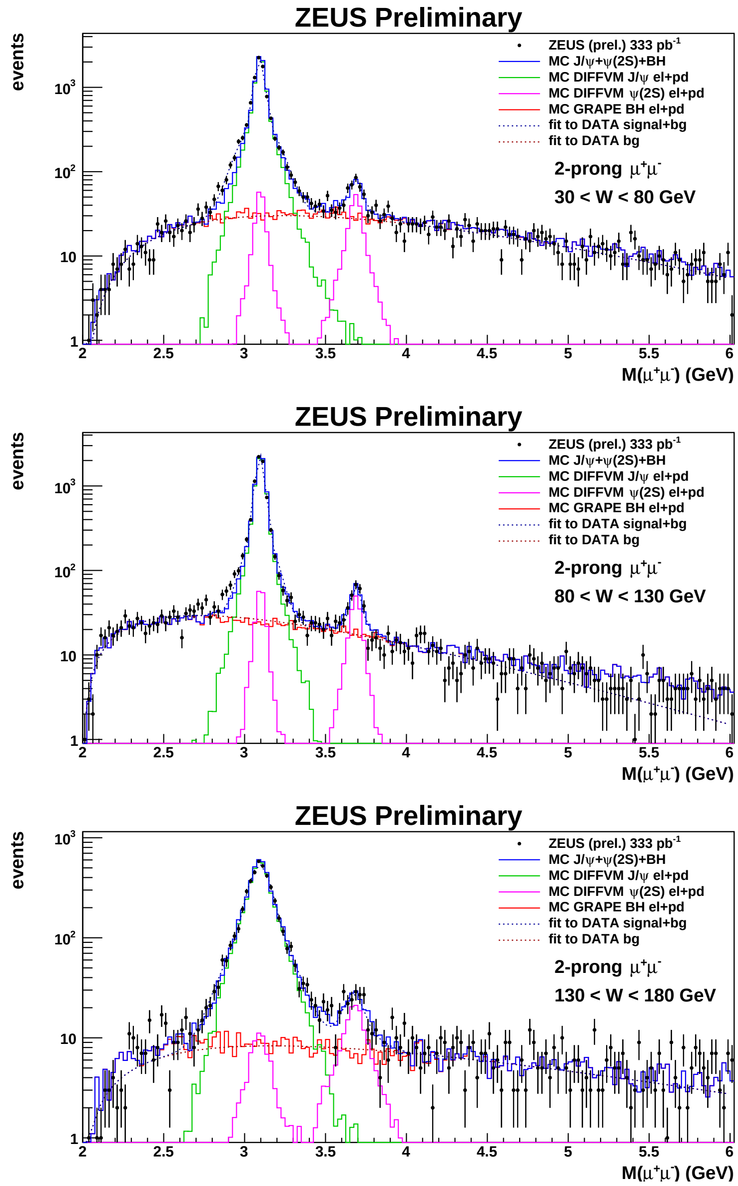

Figure 1: Measured invariant mass distribution $M(\mu^+\mu^-)$ of di-muon pairs (full dots) with error bars denoting statistical uncertainties. The data sample was splitted into three W intervals: (30-80) GeV (top), (80-130) GeV (middle) and (130-180) GeV (bottom). Monte Carlo distributions for simulated events are shown for exclusive production of J/ψ and $\psi(2S)$ (DIFFVM elastic and proton-dissociative processes) and for continuous background of muon pairs (GRAPE) from Bethe-Heitler (BH) process. The resonant background contributing to the J/ψ peak, coming from the cascade decay of $\psi(2S)$ state is also visible. Blue line represents the sum of all processes. The relative contribution of different processes was obtained from the fractional fit to the di-muon invariant mass spectrum in (2-6) GeV range. The dotted lines are the result of the double-Gaussian fit to the resonant peaks plus background shape.

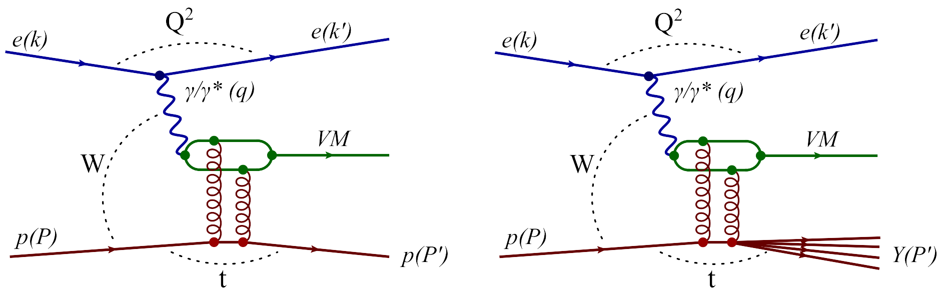

Figure 2: Lowest order diagrams for exclusive and photon-dissociative vector-meson photoproduction in ep interaction. Kinematics of the process is described by following variables: k, p, k' and p' denote the four-momenta of the incoming and outcoming electron and proton, the $\psi(2S)$ meson and the scattered proton, respectively. Then the reaction $ep \to \psi(2S)p$ is characterized by: $s = (k+P)^2$, the centre-of-mass energy squared of the electron-proton system; $Q^2 = -q^2 = -(k-k')^2$, the negative four-momentum squared of the exchanged photon; $y = (q \cdot p)/(k \cdot p)$, the fraction of the electron energy transferred to the hadronic final state in the rest frame of the initial state proton; $W^2 = (q+p)^2 = -Q^2 + 2y(k \cdot p) + M_p^2$, the centre of mass energy squared of the photon-proton system, where M_p is the proton mass; $t = (p-p')^2$, the four-momentum transfer at the proton vertex, and M_{VM}, the invariant mass of the produced vector meson.

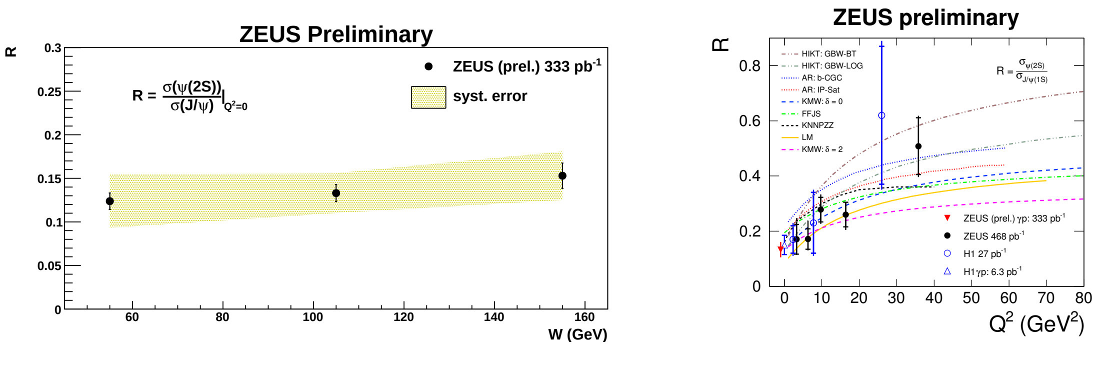

Figure 3: Mean cross section ratio R of $\psi(2S)$ to J/ψ production calculated using 2- and 4-prong channels as a function of W at $Q^2 = 0$ GeV^2 (left plot) and as a function of Q^2 (right plot). The ZEUS results (solid points) are shown compared to the previous H1 results (open points) [2, 3]. The model predictions are labeled by the names of the authors: HIKT [4], KNNPZZ [5], AR [6], LM [7], FFJS [8] and KMW [9] are shown as curves. New ZEUS preliminary result is plotted as full red triangle at $Q^2 = 0$ GeV^2.