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Photo-production of ψ(2S) Mesons at HERA

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Abstract

Measurements of the cross-section for the diffractive photo-production of ψ(2S) mesons have been made at an average photon-proton centre-of-mass energy of about 80 GeV. Identification of the mesons in the H1 detector proceeds using the decays of ψ(2S) to $J/\psi\pi^+\pi^-$, where the J/ψ subsequently decays to a lepton pair. A ratio of the cross-sections for ψ(2S) and J/ψ has been calculated for quasi-elastic production.

1 Introduction

HERA offers the opportunity to investigate the production of vector mesons at centre-of-mass photon-proton collision energies of $W_{\gamma p} \approx 100$ GeV and beyond extending, by an order of magnitude, the $W_{\gamma p}$ range over which such measurements have been made previously. This represents a tough test for models of vector meson photo-production and sheds light on the mechanisms involved.

Models of diffractive production, characterised by a colourless transfer of 4-momentum to the proton and values of z, the elasticity variable, close to 1, include the Vector Meson Dominance Model [1, 2] and QCD inspired models [3, 4]. The kinematic quantity z is defined as E_V/E_γ in the proton rest frame.

In the Vector Meson Dominance Model the interaction $\gamma p \rightarrow VX$ procedes via the exchange of a pomeron, carrying momentum but no quantum numbers. At HERA energies, where the distance over which a real photon can exist as an off-shell vector meson is much larger than the size of the proton, the formation of the vector meson and the interaction with the proton can be regarded as separate events, and the pomeron couples to the off-shell vector meson putting it on-shell. In QCD inspired models the pomeron is replaced by a gluon ladder and the differential cross-sections for diffractive vector meson production are thus related to the gluon content of the proton.

In 1994, H1 recorded data from about 3 pb^{-1} integrated luminosity of collisions between positrons of energy 27.5 GeV and protons of energy 820 GeV. For the first time, a signal for ψ(2S) mesons was observed in four prong events in H1 [5]. These events were predominantly of a diffractive nature and photo-produced, that is Q^2, the negative mass-squared of the photon transferred from the positron, very close to 0 GeV^2. A measurement has been made of the photo-production cross-section for ψ(2S) at $z > 0.95$ at an average $W_{\gamma p}$ of 80 GeV and is presented here. This has been compared to the same result for J/ψ production, and a ratio calculated.

2 Identification of ψ(2S)

In H1, the ψ(2S) mesons are identified by their decays to $J/\psi\pi^+\pi^-$, where the J/ψ subsequently decays to a muon or an electron pair. For each of these two channels, the branching ratio is 1.9 ± 0.2 % [6].

Only events in which precisely four charged tracks are observed in the H1 detector [7] are considered. Muons are identified by their traces in the liquid argon calorimeter, which are typical for minimum ionizing particles, or by tracks in the outer muon chambers. Electrons leave recognisable energy deposits in the first layers of the liquid argon calorimeter. If a lepton pair is found with an invariant mass compatible with being the decay products of a J/ψ meson, a mass difference

$$\Delta M \equiv M_{l^+l^-\pi^+\pi^-} - M_{l^+l^-}$$

is formed, assuming that the remaining two tracks in the event are pions. Wrong charge combinations are rejected. Where the four charged tracks are the decay products of a ψ(2S) meson, a value $\Delta M \approx M_{\psi(2S)} - M_{J/\psi}$ is expected.

The ΔM distributions are shown in figures 1 and 2. Signals from 'loose selections' are shown which result from minimal requirements on the quality of the reconstructed tracks corresponding to the decay particles. For the detector acceptance calculation a 'tight selection' is used, which demands that the reconstructed tracks lie in a region of the detector which is well understood. Clear signals with no background in both electron and muon channels are seen. The signals are consistent with the production of ψ(2S). Although some contribution from ψ(1D) cannot be excluded as a possibility, this is not expected by virtue of the much smaller leptonic couplings of the 1D state.

3 Cross-sections

The acceptance for ψ(2S) detection in the H1 detector using the identification above is estimated using a Monte Carlo generator [8] which has been found to model successfully J/ψ production in H1. Parameters of the generator, which is based on the Vector Meson Dominance Model, have been tuned to match the J/ψ data, and the change in acceptance due to reasonable deviations of the parameters from the chosen values is absorbed into the systematic errors. The phase space expectation for the distribution of the decay products of the ψ(2S) is modified by a factor $(M^2_{\pi^+\pi^-} - 4m^2_\pi)^2$ in the Monte Carlo to conform to previous experimental measurements [9, 10].

The insistence on precisely four identified charged tracks is found to restrict the acceptance to the kinematic region, $z > 0.95$. Moreover, rejecting events in which the scattered positron from the positron-proton collision is observed in H1 results in zero acceptance for $Q^2 > 4$ GeV^2. The $W_{\gamma p}$ range for which the ψ(2S) might be identified is 40 to 160 GeV for the muon channel and 40 to 120 GeV for the electron channel.

No attempt has been made to separate events in which the proton remains intact, 'proton elastic', from events in which the proton dissociates, 'proton inelastic'. For the acceptance calculation a mass spectrum for the proton remnant has been assumed which is consistent with the results of the analyses of J/ψ meson production at H1.

This Monte Carlo generator is found to model faithfully all important angle, momentum and kinematic distributions of the observed ψ(2S) events. The acceptance for ψ(2S) events produced in the kinematic ranges above is determined as 7.1 ± 1.4 % where the cascade J/ψ meson decays to a muon pair, and 4.7 ± 1.0 % where the decay is to an electron pair. These systematic errors arise from uncertainties in the Monte Carlo model and in the H1-detector simulation.

The positron-proton cross-section for the production of ψ(2S) in the kinematic range $z > 0.95$ and $Q^2 < 4$ GeV^2 is then measured as

$$\sigma(ep \to \psi(2S)X) = 2.3 \pm 0.8|_{sta} \pm 0.5|_{sys}\, nb \tag{1}$$

for $40 < W_{\gamma p} < 160$ GeV, identifying the J/ψ by its decay to a muon pair, and

$$\sigma(ep \to \psi(2S)X) = 1.6 \pm 0.7|_{sta} \pm 0.4|_{sys}\, nb \tag{2}$$

for $40 < W_{\gamma p} < 120$ GeV for electron pairs.

The positron-proton cross-section is related to a photon-proton cross-section by considering the positron as a source of photons, so that the interaction of interest is $\gamma p \to$

$\psi(2\mathrm{S})X$. Neglecting the small component of the ep cross-section due to the flux of photons with longitudinal polarisation, the photon flux is given by [11]

$$f_{\gamma/e} = \frac{\alpha}{2\pi}\frac{1}{yQ^2}\left(1 + (1-y)^2 - \frac{2m_e^2 y^2}{Q^2}\right) \tag{3}$$

which is convoluted with the photon-proton cross-section over the kinematic range of interest to give the positron-proton cross-section.

At $W_{\gamma p} = 80$ GeV the photo-production cross-section for $\psi(2\mathrm{S})$ mesons with $z > 0.95$ is measured as

$$\sigma_{\gamma p} = 19 \pm 6|_{sta} \pm 4|_{sys}\, nb \tag{4}$$

in the muon analysis, and

$$\sigma_{\gamma p} = 18 \pm 7|_{sta} \pm 4|_{sys}\, nb \tag{5}$$

in the electron analysis.

Combining the two results yields

$$\sigma_{\gamma p} = 19 \pm 5|_{sta} \pm 4|_{sys}\, nb \tag{6}$$

which can be compared with $119.5 \pm 11.2 \pm 12.0$ nb for J/ψ production [5], giving a ratio

$$\frac{\sigma_{\gamma p}(\psi(2S))}{\sigma_{\gamma p}(J/\psi)} = 0.16 \pm 0.06 \tag{7}$$

for $z > 0.95$ at $W_{\gamma p} = 80$ GeV, where the error quoted is a combination of statistical and systematic uncertainties.

Results from other experiments [12, 13, 14], all at $W_{\gamma p} < 20$ GeV, give a similar ratio suggesting that, at least up to HERA energies, the J/ψ to $\psi(2\mathrm{S})$ production ratio is not strongly dependent on the energy of the photon-proton collision.

4 Summary

The photon-proton cross-section for the diffractive production of $\psi(2\mathrm{S})$ mesons at HERA has been measured using the H1 detector. This measurement was made at a centre-of-mass energy of the photon-proton collision five times greater than attained at previous experiments. The result, when compared to those at lower energy, is consistent with a ratio of $\psi(2\mathrm{S})$ to J/ψ production which is independent of the centre-of-mass energy.

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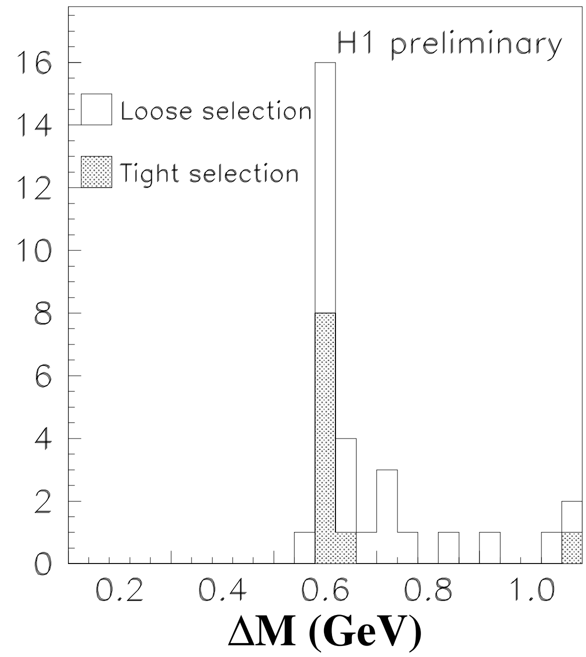

Figure 1: $\Delta M \equiv M_{\mu^+\mu^-\pi^+\pi^-} - M_{\mu^+\mu^-}$ distribution for four-prong events where a muon pair is identified satisfying $2.8 < M_{\mu^+\mu^-} < 3.4$ GeV. The unshaded region corresponds to all combinations found, shaded to events used for the cross-section calculation.

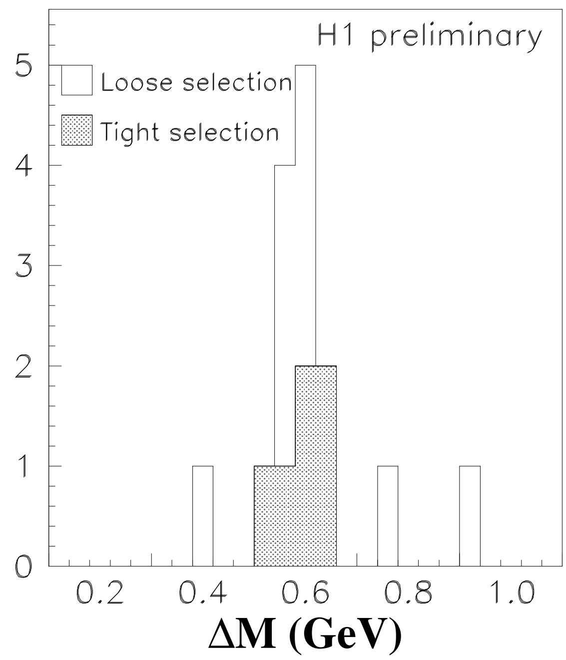

Figure 2: $\Delta M \equiv M_{e^+e^-\pi^+\pi^-} - M_{e^+e^-}$ distribution for four-prong events where an electron pair is identified satisfying $2.8 < M_{e^+e^-} < 3.4$ GeV. The unshaded region corresponds to all combinations found, shaded to events used for the cross-section calculation.