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Observation of Υ Production at HERA

H1 Collaboration

Abstract

Data collected by the H1 detector in the years 1994 to 1997 have been used to search for a signal of diffractively produced Υ ($\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$) decaying into two muons. The cross section for exclusive photoproduction at an average photon proton centre-of-mass energy of 160 GeV is determined to be $\sigma(\gamma\, p \rightarrow \Upsilon\, p) \times BR(\Upsilon \rightarrow \mu^+\mu^-) = 16 \pm 8 \pm 4$ pb (H1 preliminary).

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Parallel sessions: 7,5
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Introduction

Measurements of diffractive photoproduction of J/ψ mesons at HERA demonstrate cross sections of the order of 100 nb [1] at a photon proton centre-of-mass energy of 100 GeV. Good progress was made in describing the production properties within the framework of perturbative QCD [2, 11]. Predictions from such models lead to a cross section for Υ production about three orders of magnitude lower. Since a recent measurement of inclusive photoproduction of b quarks [3] yields a higher cross section than anticipated, the measurement of Υ mesons is interesting.

Data and Event Selection

The data used in this analysis were collected during the years 1994 to 1997 using the H1 detector [4] at the HERA collider, which was operated with positrons at an energy of 27.5 GeV and protons at 820 GeV. The data sample corresponds to an integrated luminosity of 34.5 pb^{-1}.

In order to search for exclusively produced Υ mesons the decay mode $\Upsilon \rightarrow \mu^+\mu^-$ is used and events with two high quality reconstructed tracks in the H1 detector are selected where there is no further significant activity in the tracker or in the calorimeter. The tracks must lie in the angular range $20° < \theta < 165°$, where the polar angle θ is measured with respect to the beam axis, and the direction of the outgoing proton beam is called forward, corresponding to small values of θ. Furthermore the tracks must be fitted to the event vertex within the nominal interaction zone. The two tracks must be identified as oppositely charged muons either in the muon detector (instrumented iron return yoke of the magnet) or as minimum ionizing particles in the calorimeter (Liquid Argon). In order to suppress cosmic ray events the tracks are required to have timing compatible with a possible ep interaction and a difference in polar angles of less than $165°$. The photon proton centre-of-mass energy is restricted to $70 < W_{\gamma p} < 250$ GeV. For each data taking period a set of triggers is selected which is known to work efficiently. These triggers are based on track information from proportional and drift chambers and on information from the muon detector.

The mass spectrum for the selected events is shown in fig. 1 for masses above 5 GeV. A peak is seen at $m_{\mu\mu} \sim 9.3$ GeV above a background spectrum which is mainly due to the process $\gamma\gamma \rightarrow \mu^+\mu^-$. For the evaluation of the cross section the event sample is further restricted by requiring no scattered positron visible in the detector, so that $Q^2 < 2\,\mathrm{GeV}^2$. Detectors in the forward region, close to the outgoing proton beam, are used to eliminate events in which the scattered proton dissociates.

Background and Efficiencies

In order to subtract the background and to compute efficiencies two Monte Carlo generators are used: DIFFVM [5] and LPAIR [7]. With the aid of the generator DIFFVM, where diffractive Υ events are produced with and without dissociation of the proton, the data are corrected for inefficiencies due to trigger and selection cuts. The parameters used follow those from J/ψ analyses [1], assuming they are roughly the same: the slope parameter b for the dependence of the cross section on t, which is the squared momentum transfer at the proton vertex: $d\sigma/dt \sim exp(-b|t|)$ with $b = 4$ GeV^{-2} (elastic), $b = 1.6$ GeV^{-2} (proton-dissociation); the dependence of the cross section on $W_{\gamma p}$ ($\sigma_{\gamma p} \sim {W_{\gamma p}}^{0.9}$) and on the mass of the dissociated proton system M_Y ($\sigma_{\gamma p} \sim 1/{M_Y}^{2(1+0.0808)}$).

The relative contributions from the states $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ are roughly 10:2:3 (estimated from BR$\times\Gamma_{ee}$ of each state) if the decay branching ratios into muons are taken into account (BR($\Upsilon(1S)\to \mu^+\mu^-) = 2.48\%$, BR($\Upsilon(2S)\to \mu^+\mu^-) = 1.31\%$, BR($\Upsilon(3S)\to \mu^+\mu^-) = 1.81\%$) [6]. Because of the mass resolution of the detector it is not possible to distinguish these states experimentally. The peak and width which are found in the data are compatible with the sum of the three Υ states estimated by Monte Carlo simulation.

The QED process $\gamma\gamma \to \mu^+\mu^-$, where one photon stems from the positron and the other from the proton, is simulated using the generator LPAIR. It produces elastic events and events with proton dissociation.

The efficiencies of the data selection were carefully checked in all data taking periods and the Monte Carlo simulation was corrected accordingly. For comparison with the data a fixed contribution from Υ meson production is added to the absolutely normalized $\gamma\gamma$ events so that the mass distribution is described. In fig. 2 distributions comparing data and this simulation are shown. Good agreement is observed in shape and also in the absolute cross section of the background. In the right column the distributions are shown only for those events, which have an invariant mass between 9 and 10 GeV, where the contribution by Υ meson production is maximum. The discription of the data by the simulation is found to be good.

Result

The number of events in the signal ($N_\Upsilon = 8.3 \pm 3.9$) is determined by a fit of a Gaussian plus an exponential for the background to the invariant mass distribution in the data. The resulting number of events is corrected successively for remaining background from proton dissociation (12%), for acceptance and selection efficiency (25.5%) and trigger efficiency (57.6%). Using the luminosity of 34.5 pb^{-1} an ep cross section times branching ratio is computed in the kinematic region $Q^2 < 2\ \mathrm{GeV}^2$ and $70 < W_{\gamma p} < 250$ GeV:

$$\sigma(e\,p \to e\,\Upsilon\,p) \times \mathrm{BR}(\Upsilon \to \mu^+\mu^-) = 1.4 \pm 0.7 \pm 0.4 \text{ pb (H1 preliminary).}$$

Using the improved Weizsäcker–Williams approximation [8] this is converted to a photon proton cross section at a mean $\langle W_{\gamma p}\rangle = 160$ GeV:

$$\sigma(\gamma\,p \to \Upsilon\,p) \times \mathrm{BR}(\Upsilon \to \mu^+\mu^-) = 16.0 \pm 7.5 \pm 4.0 \text{ pb (H1 preliminary)}$$

where Υ stands for the the sum over the states $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$. The systematic error is estimated by varying the background fit used to extract the number of events (15%). As a cross check on the trigger selection, cross sections were computed with two independent trigger sets and were found to agree within errors. The difference is used to estimate the systematic error on the trigger efficiency (16%). The remaining errors (13%) have been estimated for analyses of J/ψ production and are dominated by the uncertainty on the separation of elastic and proton dissociation processes.

Conclusions

We obtain a photon proton cross section times branching ratio for the sum of exclusively produced $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ of $\sigma(\gamma\, p \to \Upsilon\, p) \times$ BR$(\Upsilon \to \mu^+\mu^-) = 16.0 \pm 7.5 \pm 4.0$ pb (H1 preliminary) for $Q^2 < 2\,\mathrm{GeV}^2$ and $70 < W_{\gamma p} < 250\,\mathrm{GeV}$. A similar measurement reported by the ZEUS collaboration [9] agrees well with our result.

Calculations by Frankfurt et al. [2], based on perturbative QCD relating vector meson photoproduction to the square of the gluon density in the proton, predict a cross section times branching ratio for the sum of the three Υ states considered here of 2.7 pb in the same kinematic region using the GRV-HO [10] gluon density.

Assuming a contribution of 70 % from $\Upsilon(1S)$ to the measured cross section, the cross section for exclusive photoproduction of $\Upsilon(1S)$ is 450 ± 240 pb, roughly a factor 200 lower than the one for J/ψ at the same $W_{\gamma p}$. Calculations by Nemchik et al. [11] based on colour dipole phenomenology predict a cross section for $\Upsilon(1S)$ production of about 30 pb, again in the same kinematic region. The predictions from the different models are lower than the measurement by about two standard deviations.

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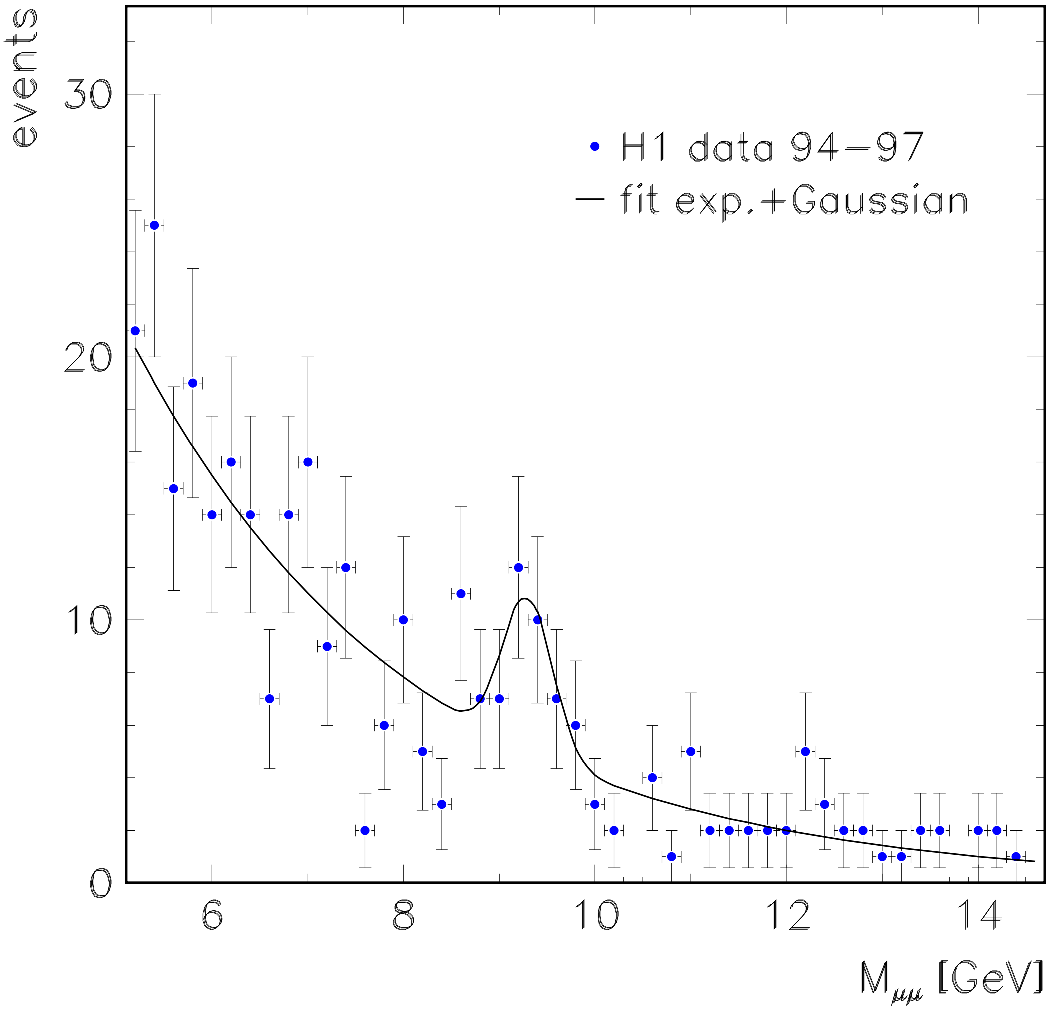

Figure 1: The invariant mass spectrum of the diffractive (elastic and proton-dissociative) two-muon events above 5 GeV for all Q^2. A fit of an exponential plus a Gaussian to the data is also shown.

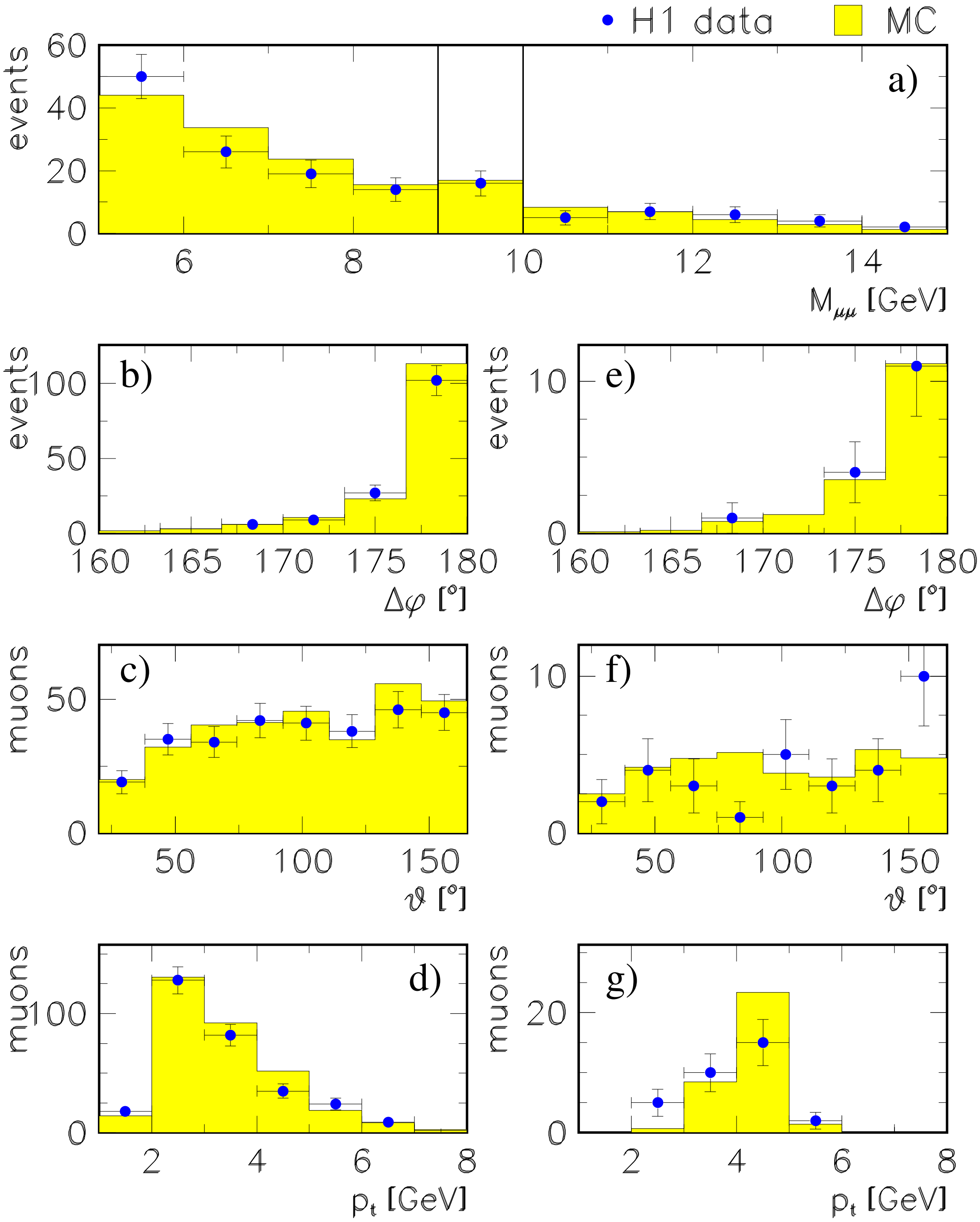

Figure 2: Comparison between data and Monte Carlo simulation for elastic two-muon events in photoproduction. a) Invariant mass of the muon pair between 5 and 15 GeV, b) and e) azimuthal opening angle of the muon pair $\Delta\phi$, c) and f) polar angle of the muons θ_μ and d) and g) transverse momentum of the muons $p_{t,\mu}$. For pictures a)-d) events with an invariant mass between 5 and 15 GeV are shown, for e)-g) only those between 9 and 10 GeV, where roughly half of the events should stem from Υ meson production. The full points are the data and the hatched histograms show the Monte Carlo simulation, which is a sum of LPAIR (normalized to the data luminosity) and DIFFVM (normalized to fit the mass peak in the data).