PROTON-DISSOCIATIVE DIFFRACTIVE PHOTOPRODUCTION OF VECTOR MESONS AT HIGH MOMENTUM TRANSFER AT HERA*

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(Received June 24, 2002)

Diffractive photoproduction of vector mesons, $\gamma p \to VY$, where Y is the proton-dissociative system, has been measured in e^+p interactions with the ZEUS detector at HERA using an integrated luminosity of 25 pb^{-1}. The differential cross section, $d\sigma/dt$, and a decay-angle analysis for ρ^0, ϕ and J/ψ mesons are presented for a photon-proton centre-of-mass energy $80 < W < 120$ GeV and $-t < 12$ GeV^2, where t is the square of the four-momentum transferred to the vector meson. The t distributions are well fit by a power law, $d\sigma/dt \propto (-t)^n$. The slope of the Pomeron trajectory, measured from the W dependence of the ρ and ϕ cross sections in bins of t, is consistent with zero. The ratios $d\sigma_{\gamma p\to\phi Y}/dt$ to $d\sigma_{\gamma p\to\rho Y}/dt$ and $d\sigma_{\gamma p\to J/\psi Y}/dt$ to $d\sigma_{\gamma p\to\rho Y}/dt$ increase with increasing $-t$. For the ρ^0 and ϕ mesons a contribution from single and double helicity flip is observed. The results are compared to expectations of theoretical models.

PACS numbers: 13.60.Le

1. Introduction

This study [1] describes measurements of proton-dissociative vector meson production, $ep \to eVN$, where $V = \rho^0, \phi, J/\psi$ and Y is the proton dissociative system. Our aim is to examine whether t, the four-momentum transfer squared between the photon and the final-state vector meson, may also serve, like the photon virtuality Q^2 or the vector meson mass, as a hard QCD scale, as predicted in [2]. In particular, the differential cross section $\frac{d\sigma}{dt}$ and the slope of the Pomeron trajectory is compared to the predictions of the pQCD-based models; as are the decay-angle distributions of the final-state mesons.

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* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

The scattered positron was detected in the Photoproduction Tagger (PT), an electromagnetic calorimeter installed 44 m from the interaction point in the direction of the outgoing positron, ensuring that the virtuality of the exchanged photon is $Q^2 < 0.02$ GeV^2. This small value of Q^2 allows a precise determination of t from the measurement of the meson transverse momentum with respect to the beam direction, p_{T} (here $t = -p_{\mathrm{T}}^2$ is a very good approximation).

The data were collected in 1996 and 1997 with the ZEUS detector at HERA and correspond to an integrated luminosity of 25 pb^{-1}.

2. Analysis

The ZEUS detector has been described in detail elsewhere [3]. The main components for this analysis are the Central Tracking Detector (CTD) [4] and the high-precision uranium-scintillator calorimeter (CAL) [5].

The study was restricted to events with (1) two well-measured tracks in the CTD having an invariant mass consistent with the mass of the vector meson under study, (2) no energy in the CAL other than that associated with either the two tracks or the dissociated-proton system Y and (3) the scattered positron detected in the PT. The selected events have a gap of at least two units of rapidity between the dissociated nucleonic system and the tracks. The γp centre-of-mass energy was restricted to the range $80 < W < 120$ GeV (where the tagging efficiency is reliably known). The trigger conditions require $-t > 1$ GeV^2.

For the simulation of the reaction $ep \to eVY$, the EPSOFT Monte Carlo generator [6] was used, reweighted to describe the data.

3. Results

3.1. Differential cross sections and cross section ratios

Figure 1 shows the differential cross sections $\frac{d\sigma}{dt}$ for the ρ^0, ϕ and $J\psi$ mesons together with pQCD BFKL calculations [7], which were fitted to the data described here. The prediction agrees well with the data. The cross sections are well described by a power dependence on t, $A\,(-t)^{-n}$ for $-t > 1.2$ GeV^2, as expected for a hard production mechanism. The fit gives $n = 3.21 \pm 0.04$ (stat.)± 0.15 (syst.) for the ρ^0, $n = 2.7 \pm 0.1$ (stat.)± 0.2 (syst.) for the ϕ and $n = 1.7 \pm 0.2$ (stat.)± 0.3 (syst.) for the J/ψ production.

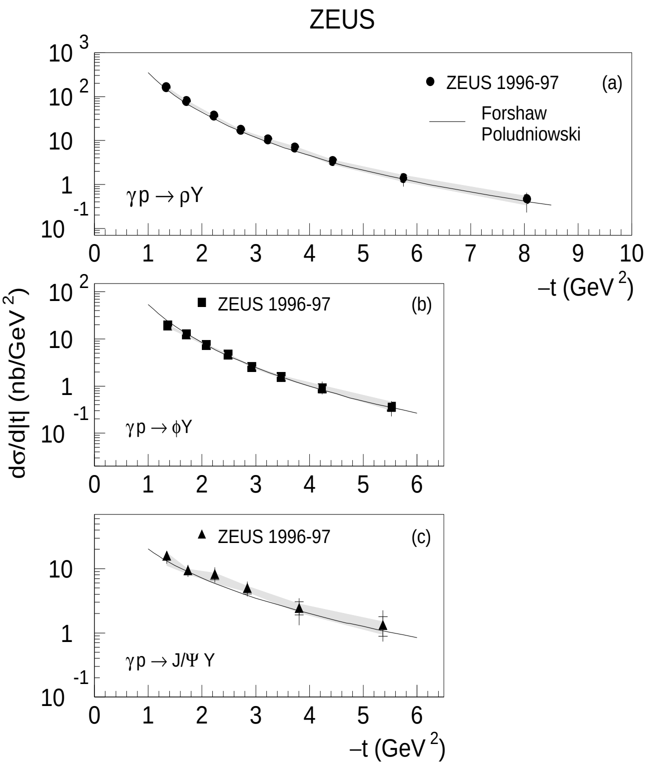

Fig. 1. The differential cross sections $\mathrm{d}\sigma/\mathrm{d}t$ for proton-dissociative photoproduction of (a) ρ^0, (b) ϕ and (c) J/ψ mesons, in the range $80 < W < 120$ GeV. The solid curves show a pQCD calculation [7]. The inner error bars indicate the statistical error, the outer bars the statistical and systematic uncertainties added in quadrature. The shaded band corresponds to the uncertainty due to the modeling of the hadronic system.

The ratios of the differential cross section $\frac{d\sigma}{dt}(\gamma p \to \phi N)/\frac{d\sigma}{dt}(\gamma p \to \rho^0 N)$ and $\frac{d\sigma}{dt}(\gamma p \to J/\psi N)/\frac{d\sigma}{dt}(\gamma p \to \rho^0 N)$ are shown in Fig. 2. A rise of the ϕ/ρ^0 ratio up to $-t \approx 4$ GeV^2 is observed, approaching the SU(4) value[1]. A clear increase of the $(J/\psi)/\rho^0$ ratio with increasing $-t$ is also observed, although the ratio is significantly smaller than the SU(4) value of 8:9 up to $-t$ values of 4 GeV^2.

[1] The SU(4) prediction, which ignores the meson mass differences, is that the coupling strengths of the photon to the ρ^0, ω, ϕ and J/ψ mesons should be in the ratios $9:1:2:8$.

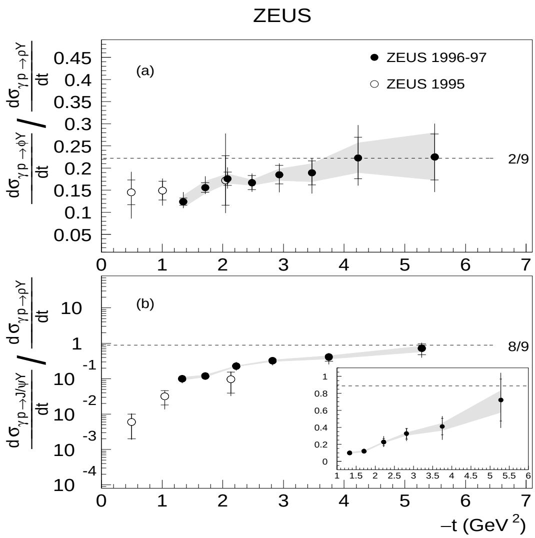

Fig. 2. The ratio of the ϕ/ρ photoproduction (a) and of the $(J/\psi)/\rho$ photoproduction (b). The inner bars indicate the statistical error and the outer bars represent the statistical and systematic uncertainties added in quadrature. The shaded bands represent the size of the uncertainties due to the modeling of the dissociative system Y.

3.2. The effective slope of the Pomeron trajectory

The effective slope of the Pomeron trajectory, α', was determined by studying the relative changes of the W dependence of the cross section as a function of t for the ρ^0 and ϕ mesons[2] [1]. The slopes are $\alpha' = -0.02 \pm 0.05(\mathrm{stat.})^{+0.04}_{-0.08}(\mathrm{syst.})$ for the ρ^0 meson and $\alpha' = -0.06 \pm 0.12(\mathrm{stat.})^{+0.05}_{-0.09}(\mathrm{syst.})$ for the ϕ meson. These values are lower than the value $\alpha' = 0.25$ GeV^{-2}, which is characteristic of soft hadronic processes at $-t < 0.5$ GeV^2 and also lower than those obtained in elastic vector-meson photoproduction at HERA for $-t < 1.5$ GeV^2 [8, 9]. This observation indicates that α' decreases with increasing $-t$. The small value for α' is consistent with pQCD expectations [10, 11].

3.3. Decay-angle analysis for the ρ^0 and ϕ mesons

The angular distributions of the meson decay products were used to determine some of the ρ^0 and ϕ spin-density matrix elements. From the decay angular distribution $W(\cos\Theta, \varphi, \Phi)$ [12], where Θ, φ and Φ are the decay

[2] The intercept of the Pomeron trajectory is not measured, since it is affected by large corellated systematic uncertainties.

angles defined in the s-channel helicity frame[3], three matrix elements were evaluated: r_{00}^{04}, corresponding to the probability that the meson is produced in the helicity 0 state and $\mathrm{Re}\,[r_{10}^{04}]$ and r_{1-1}^{04} corresponding to the interference between the helicity non-flip amplitude and single or double helicity-flip amplitude, respectively. If s-channel helicity conservation (SCHC) holds, the matrix elements r_{00}^{04}, $\mathrm{Re}\,[r_{10}^{04}]$ and r_{1-1}^{04} are zero.

In Fig. 3 the values of r_{00}^{04} and r_{1-1}^{04} for the ρ^0 and ϕ mesons are displayed as function of t, together with ZEUS measurements at lower $-t$ [13]. The small values of r_{00}^{04} indicate that the helicity single-flip probability is small over the t entire range. However, the non-zero values of $\mathrm{Re}\,[r_{10}^{04}]$ indicate a helicity single-flip contribution at the level of a few percent. The non-zero values of r_{1-1}^{04} show clear evidence for a helicity double-flip contribution.

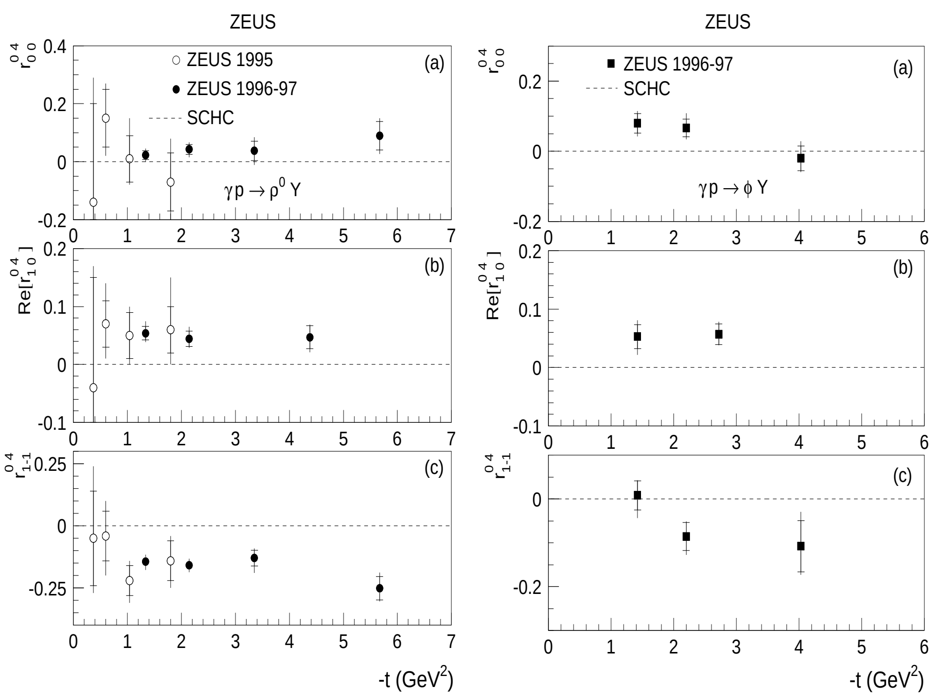

Fig. 3. The values of (a) r_{00}^{04}, (b) $\mathrm{Re}\,[r_{10}^{04}]$ and (c) r_{1-1}^{04} for proton-dissociative ρ^0 (left) and ϕ (right) photoproduction as a function of $-t$. The inner bars indicate the statistical error and the outer bars represent the statistical and systematic uncertainties added in quadrature. The dashed line shows the SCHC prediction.

[3] The s-channel helicity frame is defined as the rest frame of the meson in which the meson direction in γp centre-of-mass frame is taken as the quantization axis.

3.4. Conclusions

In conclusion, these results imply that large values of $-t$ can provide a suitable hard scale for perturbative QCD calculations.

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