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Polarisation Study of High Q^2 Elastic ρ Meson Production at HERA

H1 Collaboration

Abstract

Results on the decay angular distributions of ϱ mesons elastically produced at HERA are presented, for high photon virtuality ($Q^2 \;\; > 8$ GeV^2) and high $\gamma^* p$ centre of mass energy ($W \;\; \simeq 100$ GeV). The $\cos\theta$ distribution indicates that the final state ϱ mesons are mostly longitudinally polarised. The ψ distribution in combination with the $\cos\theta$ distribution, supports the s–channel helicity conservation (SCHC) hypothesis. The ratio R of the cross sections for ϱ production by longitudinal and transverse virtual photons is computed for bins in Q^2 or W.

1 Introduction and Data Selection

The e^+p collider HERA allows the study of elastic ϱ meson production by the reaction:

$$e^+ + p \rightarrow e^+ + p + \varrho, \tag{1}$$

the beam energies being, respectively, 27.5 GeV and 820 GeV for the positrons and the protons. This reaction is studied at high photon virtuality ($Q^2 > 8$ GeV^2), high $\gamma^* p$ centre of mass energy ($W \simeq 100$ GeV) and low $|t|$ values ($|t| < 0.5$ GeV^2), where t is the 4–momentum transfer squared to the proton. The total integrated luminosity used for this analysis is 2.8 pb^{-1}.
High Q^2 elastic ϱ events are selected with the H1 detector by asking a positron scattered in the backward[1] electromagnetic calorimeter, two tracks in the central tracker corresponding to an invariant mass $0.6 < m_{\pi^+\pi^-} < 1.0$ GeV/c^2 and no other track or energy cluster above noise in the detector. A proper elastic selection is ensured by the use of the very forward detectors that veto the proton dissociative background. The amounts of diffractive background with proton dissociation and of non–resonant background (attributed mostly to photon dissociation with additional non detected particles) are, respectively, estimated to be $9 \pm 8\%$ and $11 \pm 6\%$. The kinematics of the events are computed using the double angle method (see [1]).
Selection criteria, efficiencies, backgrounds and resolutions are discussed in detail in [1], where the total and differential cross sections are studied. Here we restrict to results concerning the decay angular distributions and the polarisation state of the virtual photon.

2 Decay angle definitions

The decay of ϱ mesons is studied in the s–channel helicity system, the ϱ direction being taken as the quantization axis in the $\gamma^* p$ center-of-mass system (cms). Three angles can be defined. The polar (θ) and azimuthal (φ) angles of the positive pion from the ϱ meson decay in the $\pi^+\pi^-$ cms, and the angle ϕ between the ϱ production plane and the electron scattering plane. The decay angular distribution W($\cos\theta$, φ, ϕ) is related to the spin density matrix elements by the formalism presented in [2]. The s–channel helicity conservation (SCHC) hypothesis states that the helicity of the virtual photon is retained by the ϱ meson. In this case the angular distribution reduces to W($\cos\theta$, ψ), where $\psi = \phi - \varphi$ is the angle between the ϱ decay plane and the lepton scattering plane. Because of the limitation in statistics and in resolution, the analysis is limited here to the integrated distributions in $\cos\theta$ and ψ. In spite of an important smearing on the angles ϕ and φ, the strong correlation between them allows the measurement of ψ with a good accuracy.

[1] The forward (+z) direction is defined as that of the incident proton beam, the backward direction is that of the positron beam.

3 $\cos\theta$ distribution

After integration over the angles φ and ϕ, the W($\cos\theta$, φ, ϕ) distribution becomes

$$W(\cos\theta) \propto 1 - r^{04}_{00} + (3\ r^{04}_{00} - 1)\ \cos^2\theta. \tag{2}$$

This equation depends only on the density matrix element r^{04}_{00}, which represents the probability of finding the ϱ meson in the helicity state 0 (longitudinal polarisation).
With the H1 detector, the $\cos\theta$ variable is well measured, the resolution being 2.5%. The acceptance corrected $\cos\theta$ distribution is shown in Fig. 1a. After correction for detector effects and subtraction of the non–resonant background, assumed to be flat in $\cos\theta$ [1], the fit of eq.(2) to this distribution gives

$$r^{04}_{00} = 0.73 \pm 0.05 \pm 0.02. \tag{3}$$

The first error is statistical, the second reflects the uncertainty on the background subtraction. The quality of the fit is good: $\chi^2 = 5.3/6.0$ dof. The final state ϱ mesons are thus observed to be mostly longitudinally polarised.

4 ψ distribution and SCHC

Assuming s–channel helicity conservation (SCHC), the integration of the W($\cos\theta$, ψ) distribution over $\cos\theta$ gives:

$$W(\psi) = \frac{1}{2\pi}\ (1 + 2\ \varepsilon\ r^{1}_{1-1}\ \cos(2\psi)), \tag{4}$$

where ε is the polarisation parameter (at HERA, $\langle\varepsilon\rangle = 0.99$) [1].
The resolution on the ψ angle is about 25 mrad. A fit of eq.(4) to the data (Fig. 1b) gives

$$r^{1}_{1-1}\ =\ 0.14\ \pm\ 0.05\ \pm\ 0.01. \tag{5}$$

The first error is statistical, the second reflects the uncertainty on the background subtraction. This result is corrected for detector effects and non–resonant pion background, assuming that it has a flat distribution in ψ. The quality of the fit is good: $\chi^2 = 10.1/10.0$ dof., while it is 17.0/11.0 dof. for a linear dependence.
If in addition to SCHC, the exchange in the t-channel has natural spin–parity, r^{1}_{1-1} is related to r^{04}_{00} by:

$$r^{1}_{1-1} = 1/2\ (1 - r^{04}_{00}). \tag{6}$$

Using this relation and the r^{04}_{00} parameter measured in (3), one finds:

$$r^{1}_{1-1}\ =\ 0.135\ \pm\ 0.025\ \pm\ 0.01. \tag{7}$$

The agreement of this result with the fitted value (5) of r^{1}_{1-1} supports the SCHC hypothesis.
In photoproduction, the final state ϱ mesons are observed to have the same transverse polarisation as the photon, both in fixed target experiments and at HERA [3].

$40 < W < 140$ GeV/c^2	
$8 < Q^2 < 12$ GeV^2	$12 < Q^2 < 50$ GeV^2
$R = 2.2\ ^{+0.8}_{-0.5}$	$R = 4.0\ ^{+2.4}_{-1.2}$

$8 < Q^2 < 50$ GeV^2	
$40 < W < 80$ GeV/c^2	$80 < W < 140$ GeV/c^2
$R = 2.2\ ^{+0.8}_{-0.5}$	$R = 3.7\ ^{+1.9}_{-1.1}$

Table 1: Values of $R = \sigma_L\ /\sigma_T$ in different Q^2 and W domains.

In leptoproduction, the SCHC hypothesis has been tested in several experiments. At low Q^2 ($Q^2\ < 4$ GeV^2) and low W ($2 < W < 5$ GeV), the SCHC hypothesis is verified within errors [4a,c-e]. In the same kinematical domain [4b] and at higher energy ($8 < W < 20$ GeV) [5], a limit on the helicity single flip amplitude is found to be of 15 $\pm$ 8 %. At higher Q^2 ($2 <\ Q^2\ < 25$ GeV^2) and W ($8 < W < 20$ GeV), the results of the EMC Collaboration [6a-b] were interpreted as indicating a substantial violation of SCHC. However, the NMC analyses [6c-d] do not confirm this conclusion, and an explanation for the discrepancy is presented [6c].
In summary, the elastic production of ϱ mesons by real and virtual photons is dominated by s–channel helicity conservation, in a wide Q^2 and W range ($0 < Q^2 < 40$ GeV^2 and $2 < W < 140$ GeV).

5 R parameter

Assuming the validity of s–channel helicity conservation, as suggested by the present data, the matrix element r^{04}_{00} is related to R, the cross section ratio for ϱ production by longitudinal and transverse virtual photons:

$$R = \sigma_L\ /\sigma_T = \frac{1}{\varepsilon}\ \frac{r^{04}_{00}}{1 - r^{04}_{00}}. \tag{8}$$

With the value (3) of r^{04}_{00}, R is measured to be

$$R = 2.7\ ^{+0.7}_{-0.5}\ ^{+0.3}_{-0.2}. \tag{9}$$

This result is presented in Fig. 1c together with fixed target measurements[2]. Compared to the photoproduction results, the virtual photon cross section is observed to be increasingly longitudinally polarised when Q^2 rises. Furthermore, a possible indication for an increase of R with Q^2 and with W is observed using only the H1 data (see Table 1). Such a behaviour of R is predicted by most models for ϱ meson electroproduction [1].

[2] EMC measurements with largest errors have been omitted.

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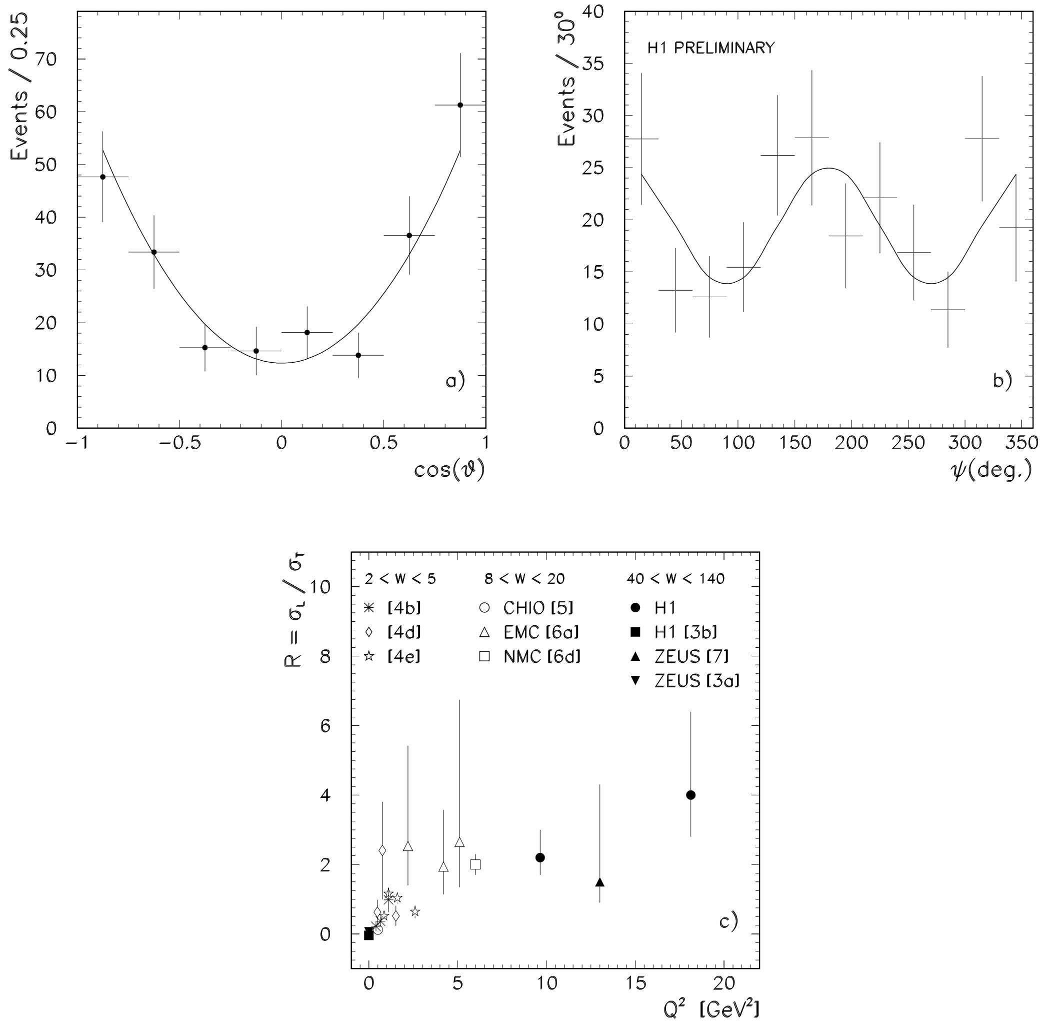

Figure 1: a) $\cos\theta$ distribution, the superimposed curve being the result of a fit of eq. 2 to this distribution; b) ψ distribution, the superimposed curve being the result of a fit of eq. 4 to this distribution; c) Q^2 dependence of $R = \sigma_L/\sigma_T$ from several experiments.