Recent Results from Decay-Angle Analyses of ρ^0 Photoproduction at High Momentum Transfer from ZEUS

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Recent results from decay-angle analyses of ρ^0 photoproduction are presented and discussed in the context of earlier measurements at lower energy and lower momentum transfer.

We report recent preliminary results on decay-angle analyses of ρ^0 photoproduction at HERA. Measurements of diffractive vector meson production at HERA have stimulated phenomenological descriptions based on perturbative QCD, in which the hard scale is provided either by the virtuality of the exchanged photon or by the mass of the vector meson. Further theoretical studies have proposed that this scale may be given by the momentum transferred to the proton as well [1]. These studies make specific predictions for the helicity of the photoproduced ρ^0, which we derive from the angular distribution of the pions produced in its decay. By studying the photoproduction of this light meson, we address the issue of whether the momentum transferred to the proton can serve as a perturbative scale.

Our analyses are based on two distinct data samples corresponding to integrated luminosities of 3 pb^{-1} and 27 pb^{-1}, the first recorded in 1995 [2,3] and the second recorded in 1996 and 1997 [4]. During these years HERA operated beams of 27.5 GeV positrons and 820 GeV protons. The trigger conditions required the scattered positron to be detected in a special-purpose tungsten/scintillator calorimeter located 3 cm from the positron beam axis, 44 meters distant from the nominal e$^+$p interaction point in the positron-beam flight direction. The acceptance of this photoproduction tagger is defined by the energy lost by the positron to the photon which interacts with the proton, thus determining the center-of-mass energy of the photon-proton system, W ($80 < W < 120$ GeV). Since the transverse momentum of the final-state positron is thus required to be small ($Q^2 < 0.01$ GeV^2), the transverse momentum of the ρ^0 ($p_{\rm t}$) detected in the central detector via its dipion decay provides an accurate approximation for the momentum transferred to the proton (t) via $t \simeq -p_{\rm t}^2$. Offline data selection criteria included the reconstruction of exactly two tracks from the interaction vertex and rejected events with calorimetric energy deposits in the rear and barrel sections of the calorimeter which were not associated with the extrapolation of either track. These criteria resulted in a semi-exclusive topology with a gap between the forward region of the event and the two tracks of at least two units of rapidity. For the decay-angle investigations at high $|t|$ presented here, the squared transverse momentum of the two-pion system relative to the beam axes was required to exceed 1 GeV^2 in the 1996/97 event sample. Information from the forward calorimeter was used to distinguish elastic from proton-dissociative events in the 1995 data sample, while for the 1996/97 data at higher $|t|$ no attempt was made to exclude the small elastic contribution. The 1995 sample consists of about 2000 events and the 1996/97 sample of about 20000 events.

The decay-angle distribution, parameterized in terms of combinations of spin-density matrix elements in the Schilling-Wolf convention [5], r_{ij}^{04}, is given by

$$W(\theta_h,\phi_h)=\frac{3}{4\pi}\left[\frac{1}{2}\left(1-r_{00}^{04}\right)+\frac{1}{2}\left(3r_{00}^{04}-1\right)\cos^2\theta_h - \sqrt{2}\mathrm{Re}(r_{10}^{04})\sin 2\theta_h\cos\phi_h - r_{1-1}^{04}\sin^2\theta_h\cos 2\phi_h\right],$$

where θ_h and ϕ_h are the polar and azimuthal

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angles of the positively-charged pion relative to the z-axis defined as the direction opposite the final-state proton system in the ρ^0 rest frame, i.e. the direction of the ρ^0 momentum in the photon-proton center-of-mass frame. This choice of z-axis defines the 's-channel helicity frame'. The origin of the azimuthal angle is defined by the ρ^0 production plane. The three-dimensional distribution has been averaged over the azimuthal angle between the positron scattering plane and the ρ^0 production plane, and thus no longer distinguishes the photon helicity states ± 1. Figure 1 shows the results for the combinations of matrix elements obtained from a least-squares minimization procedure in which they served as fit parameters. The systematic uncertainties are dominated by the uncertainty in the acceptance corrections. Slightly different dipion mass ranges were used in the two studies: $0.55 < M_{\pi\pi} < 1.2$ GeV for the 1995 data and $0.45 < M_{\pi\pi} < 1.1$ GeV for the 1996/97 data sample. The results are compared to the results at lower $|t|$ for the elastic reaction obtained with 9 GeV photons from a backscattered laser beam at SLAC incident on a hydrogen bubble chamber [6]. Also shown are the ZEUS 1994 results for elastic ρ^0 photoproduction at low $|t|$ [7]. The parameter r_{00}^{04}, which is proportional to the square of the amplitude for producing ρ^0 mesons in helicity state 0, is consistent with zero over the entire range in $|t|$. The combination Re r_{10}^{04}, which is predominantly sensitive to the interference between the helicity-conserving amplitude and the single-flip amplitude, shows slight evidence for a single-flip contribution in both the SLAC data and the high-$|t|$ ZEUS results. A clear indication of a double-flip contribution is shown by the measurements of r_{1-1}^{04} at high $|t|$, consistent with the SLAC results. There is no evidence for any difference between the angular distributions in the elastic and proton-dissociative production processes.

In order to estimate the effect on the angular distributions of a hypothesized dipion background to ρ^0 decay, the decay-angle analysis was repeated for restricted dipion mass ranges above ($0.77 < M_{\pi\pi} < 1.0$ GeV) and below ($0.6 < M_{\pi\pi} < 0.77$ GeV) the nominal value for the ρ^0 mass. While the above conclusions for r_{00}^{04}

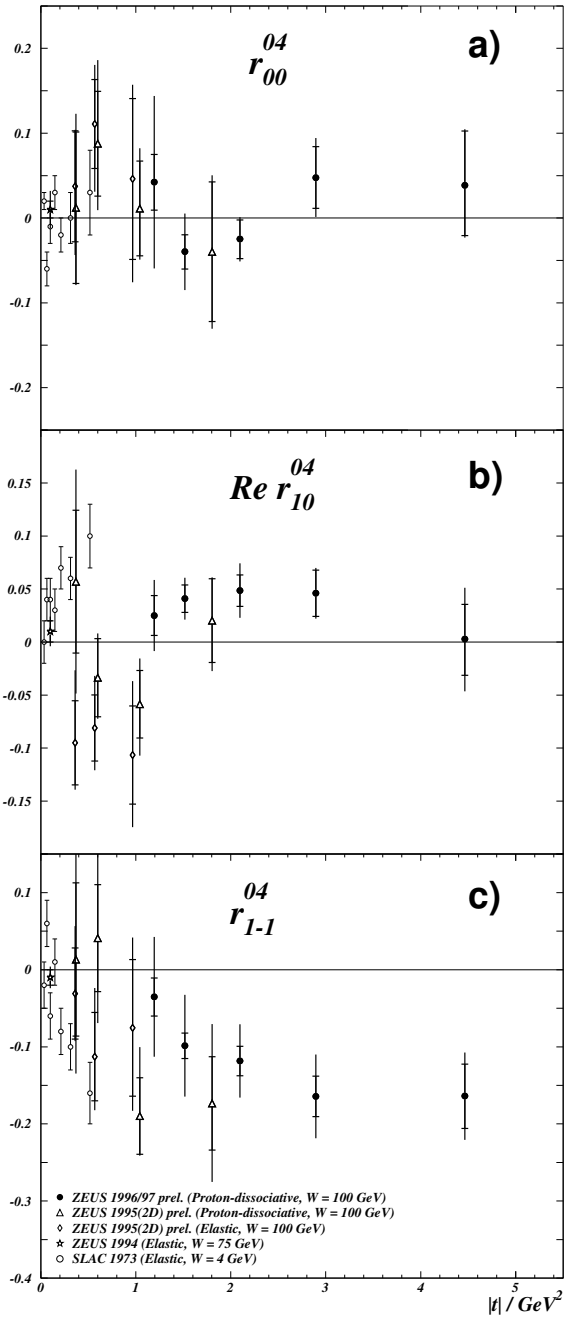

Figure 1. Measurements of the combinations of matrix elements a) r_{00}^{04}, c) Re r_{10}^{04}, c) r_{1-1}^{04} for the diffractive photoproduction of pion pairs. See text for full description

and r^{04}_{1-1} were found to apply also to each mass range separately, the observed value for Re r^{04}_{10} depends significantly on the mass range chosen, as shown in Fig. 2. The extraction of the ρ^0 spin-

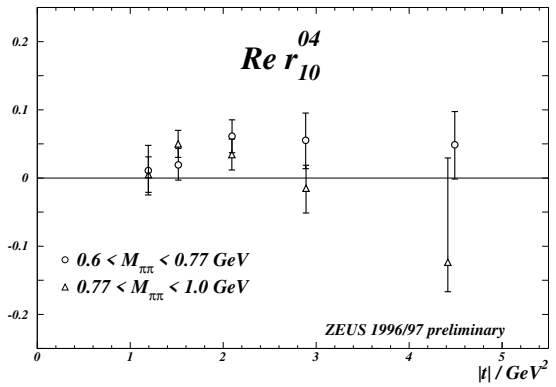

Figure 2. Results for Re r^{04}_{10} at high $|t|$ restricted to the dipion mass ranges $0.6 < M_{\pi\pi} < 0.77$ GeV and $0.77 < M_{\pi\pi} < 1.0$ GeV

density matrix elements from these angular distributions awaits the understanding of this dependence on the dipion invariant mass.

The decay-angle analysis was also performed in the Gottfried-Jackson frame, where the z-axis is defined to be the direction of the photon momentum in the photon-proton center-of-mass system, boosted to the ρ^0 rest system. The angle between these two axes approaches 180° in the limit $|t| \gg M^2_{\pi\pi}$. For this study the r^{04}_{ij} were determined via one-dimensional fits to acceptance-corrected angular distributions in $\cos\theta$ and ϕ, and consistency with the two-dimensional fits described above was verified for the measurements in the helicity frame. Figure 3 shows the extension of the low energy, low $|t|$ SLAC data to higher $|t|$, whereby here the 5 GeV photon data [8] from SLAC are used, since the frame comparison for the 9 GeV data was not published. Our results confirm the trends observed at low energy in each of the two frames.

In summary, decay-angle analyses of ρ^0 photoproduction have been extended to higher values of $|t|$ at $W \simeq 100$ GeV. The violation of s-channel helicity conservation observed at lower

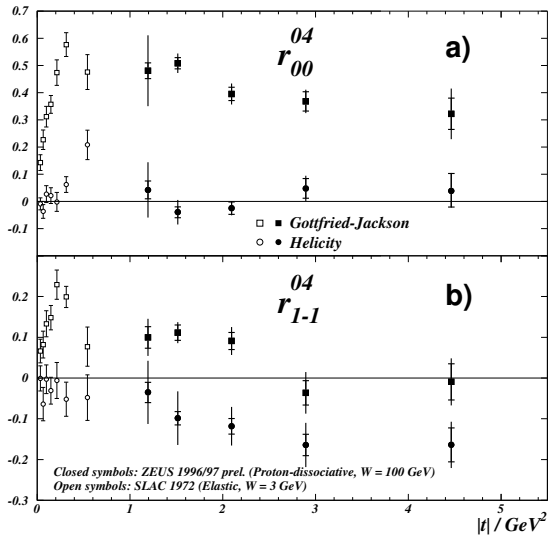

Figure 3. Comparison of the combinations of spin-density matrix elements determined in the helicity and Gottfried-Jackson frames for a) r^{04}_{00} and b) r^{04}_{1-1}

energy and lower momentum transfer is confirmed by the new results. More work is needed to understand the dependence of the extracted spin-density matrix elements on dipion invariant mass.

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