Exclusive ρ^0 electroproduction on transversely polarized protons

The HERMES collaboration

In exclusive ρ^0 electroproduction $e + p \rightarrow e' + \rho^0 + p'$ an incoming electron scatters from a proton by exchanging a virtual photon, producing a ρ^0-meson while leaving the proton intact. Data for this reaction can provide new information about the structure of the nucleon. At leading order, i.e., when the wave length of the virtual photon is sufficiently small, the cross section can be written in terms of so-called generalized parton distributions (GPDs). GPDs provide a tree-dimensional representation of the structure of a nucleon at the partonic (quark-gluon) level. They are related to the standard parton distribution functions, which describe the distribution of the momentum of the partons of a certain type in a nucleon, and nucleon form factors, which describe the spatial distribution of charge and magnetization. A sum rule has been derived that relates GPDs to the contribution of the total angular momentum of the quarks in a nucleon to the nucleon spin.

Production of ρ^0-mesons is sensitive to the GPDs H and E. In the cross section for the reaction on an unpolarized proton the contribution of E is generally small compared to the contribution of H. However, if the proton is transversely polarized, i.e., the spin of the proton is perpendicular to the direction of the incoming electron, one can measure the cross section as a function of the angle of the produced ρ^0-meson with respect to the direction of that spin. To reduce experimental uncertainties, this is done twice by reversing the direction of the polarization. The difference in the cross section for the two directions divided by their sum is defined as the asymmetry. This asymmetry depends almost linearly on the GPD E.

The cross section and asymmetry depend on four angles, two of which are connected with the direction of the produced ρ^0-meson and the polariztion direction, and two are connected with the direction of the π^+ and π^-, in which the ρ^0 decays. The dependence can be parametrized with sinus and cosinus functions of combinations of these angles. The amplitudes of these functions can be written in terms of spin density matrix elements (SDMEs). These SDMEs can be labeled according to the polarizations of the virtual photon and of the produced ρ^0-meson. By using the angular distribution of the ρ^0 and of its decay pions, one can separate the contributions of produced ρ^0 mesons with longitudinal and with transverse polarization. However, there is no direct information on the polarization of the virtual photon. If s-channel helicity conservation (SCHC) holds, the helicity of the virtual photon is transfered to the produced vector meson, and thus production of a longitudinally polarized ρ^0-meson is due to a longitudinal virtual photon. Measurements have shown that SCHC holds reasonably well for exclusive electroproduction of ρ^0 mesons on an unpolarized target at HERMES kinematics.

In this paper, measurements of exclusive ρ^0 electroproduction on transversely polarized protons are presented. For the first time, values of the spin density matrix elements and the transverse target-spin asymmetry for this process were determined, extending the study of SDMEs and of SCHC to the case of transverse target polarization and providing useful data for modeling GPDs.

The experiment was performed with 27.6 GeV electron or positron beams from HERA at DESY impinging on a transversely polarized hydrogen target. The scattered electrons and the pions from the decay of the produced ρ^0-meson were detected in the HERMES spectrometer, which consists of a large magnet and different types of detectors to measure the trajectory of a particle in the magnetic field and to determine the particle type.

The SDMEs discussed above were determined by fitting the angular distributions for the two target polarization states using maximum-likelyhood estimation. First the 15 'unpolarized' SDMEs were determined and then the 30 polarized ones, keeping the unpolarized SDMEs fixed. The results for the polarized SDMEs are shown in Fig. 1. Almost all of them are consistent with zero within 1.5σ, where σ represents the total uncertainty in the value of an SDME. This indicates that SCHC is fairly well obeyed in the case of polarization. However, there are some exceptions. For instance, the SDME $\mathrm{Im}\, n^{0\,0}_{0+}$ deviates from zero by more than 3σ. This SDME corresponds to the production of a transversely polarized ρ^0 by a longitudinal photon. Also in the unpolarized case SDMEs for such a transition were found to be non-zero.

If one neglects terms that require a double helicity flip, the leading order term in the asymmetry can be calculated from the SDMEs, which yields the value -0.035 ± 0.103 Some recent GPD-based calculations of this asymmetry give values of -0.03 to 0.02, consistent with the data.

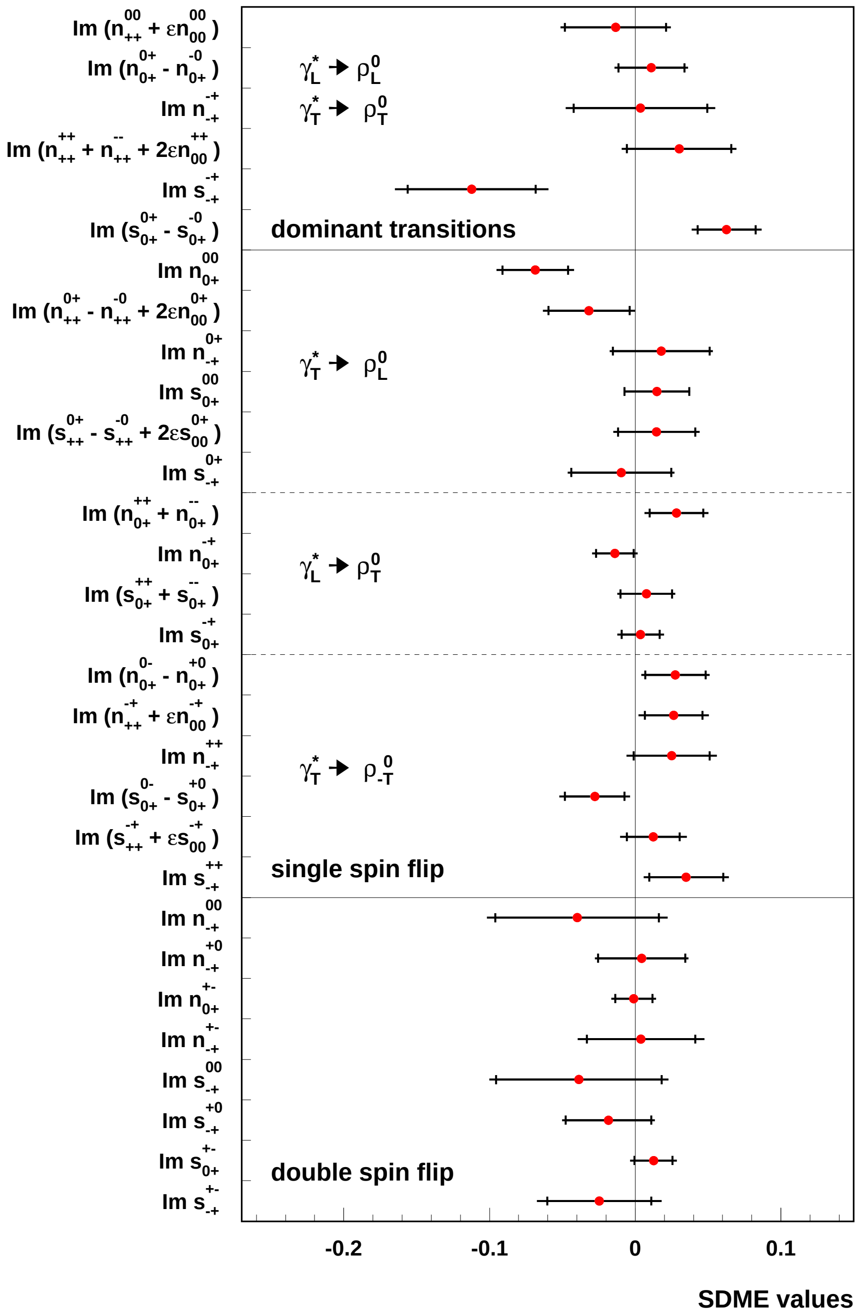

FIG. 1: Values of SDMEs, or combinations thereof, for a transversely polarized proton target and an unpolarized beam, extracted from the 2002 – 2005 HERMES exclusive ρ^0 electroproduction data. The SDMEs are sorted into three categories, which are separated from each other by the solid horizontal lines. From top to bottom: SDMEs containing s-channel helicity-conserving amplitudes, combinations containing at least one s-channel helicity-changing amplitude, and SDMEs containing two s-channel helicity-changing amplitudes. Within the second category the combinations are sorted into three groups associated with different virtual photon and ρ^0 polarizations. The inner error bars represent the statistical uncertainties. The full error bars represent the quadratic sum of the statistical and systematic uncertainties. In addition there is an overall scale uncertainty of 8.1% due to the uncertainty in the target polarization.