Transverse Target-Spin Asymmetry of Exclusive ρ^0 Meson Production on Proton at HERMES

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Preliminary measurements are reported on the azimuthal single-spin asymmetry of exclusive ρ^0 mesons for a transversely polarized hydrogen target at HERMES using the 27.6 GeV HERA positron beam. Within the generalized parton distribution (GPD) formalism, this asymmetry is sensitive to the total angular momentum of quarks and gluons in the nucleon. Since the GPD formalism is only valid for mesons produced by longitudinal photons, the transverse target-spin asymmetry of longitudinal ρ^0 mesons is extracted assuming s-channel helicity conservation and compared to theoretical calculations.

1 Introduction

Hard exclusive meson production in deep inelastic lepton scattering provides access to the unknown generalized parton distributions (GPDs) of the nucleon [2]. For such reactions, it has been shown that for longitudinal virtual photons, the $\gamma^* p$ amplitude can be factorized into a hard lepton-scattering part and two soft parts which parameterize the structure of the nucleon by GPDs and the structure of the produced meson by distribution amplitude [3]. GPDs reflect the 3-dimensional structure of the nucleon and contain information about the total angular momentum carried by partons in the nucleon. Hard exclusive production of ρ^0 mesons is sensitive to the GPDs H and E which are the ones related to the total angular momenta J^q and J^g of quarks and gluons in the nucleon [4]. The GPD H is already somewhat constrained, while the GPD E is still unknown. In the case of a transversely polarized target, the interference between the GPDs H and E was shown to lead to a transverse target-spin asymmetry (TTSA) [5]. In contrast to the cross section measurements, the TTSA depends linearly on the helicity-flip distribution E with no kinematic suppression of its contribution with respect to the other GPDs. Therefore the TTSA of exclusive ρ^0 production can constrain the total angular momenta J^q and J^g.

2 TTSA of longitudinal ρ^0 mesons

For an unpolarized (U) beam and a transversely (T) polarized target the TTSA A_{UT} is defined as

$$A_{UT} = \frac{1}{P_T} \frac{d\sigma(\phi, \phi_s) - d\sigma(\phi, \phi_s + \pi)}{d\sigma(\phi, \phi_s) + d\sigma(\phi, \phi_s + \pi)}, \tag{1}$$

where the target polarization P_T is defined w.r.t. the lepton beam direction and the angles ϕ and ϕ_s are the azimuthal angles of, respectively, the produced ρ^0 meson and the target

spin vector around the virtual photon direction w.r.t. the lepton scattering plane (see Figure 1) [6].

The cross section of exclusive ρ^0 production can be factorized in terms of angular dependent and angle-independent parts:

$$\frac{d\sigma}{dx_B \, dQ^2 \, dt' \, d\phi \, d\phi_s} = \frac{1}{4\pi^2} \frac{d\sigma}{dx_B \, dQ^2 \, dt'} W(x_B, Q^2, t', \phi, \phi_s), \qquad (2)$$

where x_B is the Bjorken scaling variable, Q^2 is the squared virtual-photon four-momentum, $t' = t - t_0$. Here $-t$ is the squared four-momentum transfer to the target and $-t_0$ represents the minimum value of $-t$.

The complete expression for the cross section of ρ^0 production is given in [7]. The angular distribution $W(\phi, \phi_s)$ can be written[a] in terms of asymmetries:

$$W(\phi, \phi_s) = \widehat{W}_{UU}(1 + A_{UU}(\phi) + P_T A_{UT}(\phi, \phi_s)), \qquad (3)$$

where $A_{UU}(\phi) = W_{UU}(\phi)/\widehat{W}_{UU}$ is the unpolarized asymmetry with $\widehat{W}_{UU}$, $W_{UU}(\phi)$ being the unpolarized angular distributions and $A_{UT}(\phi, \phi_s) = W_{UT}(\phi, \phi_s)/\widehat{W}_{UU}$ is the transverse asymmetry with the transversely polarized angular distribution $W_{UT}(\phi, \phi_s)$.

Since the factorization theorem is proven for longitudinal photons only [3], the asymmetry of ρ^0 mesons induced from longitudinal photons is of theoretical interest. Under the assumption of s-channel helicity conservation (SCHC), which implies that a longitudinal vector meson originates from a longitudinal photon, the longitudinal component of the asymmetry is obtained experimentally through the decay angular distribution of ρ^0 ($\rho^0 \to \pi^+\pi^-$). Each ρ^0 helicity state (L, T) results in a characteristic dependence of

Figure 1: Definition of ϕ and ϕ_s angles.

the $\gamma^* p$ cross-section on the θ_π polar angle of π^+ in the ρ^0 rest frame [7]. The interference terms between different helicities of the ρ^0 production are canceled if the cross section is integrated over the φ_π azimuthal decay angle of π^+ in the ρ^0 rest frame.

The total angular distribution $W(\cos\theta_\pi, \phi, \phi_s)$, including the dependence on the π^+ polar angle, can be written separately for longitudinal ρ^0_L and transverse ρ^0_T mesons:

$$
\begin{aligned}
W(\cos\theta, \phi, \phi_s) \quad \propto \quad & \left[\cos^2\theta_\pi \, \widehat{W}_{UU}^{\rho_L} \left(1 + A_{UU}^{\rho_L}(\phi) + P_T A_{UT}^{\rho_L}(\phi, \phi_s) \right) \right. \\
+ \quad & \left. \sin^2\theta_\pi \, \widehat{W}_{UU}^{\rho_T} \left(1 + A_{UU}^{\rho_T}(\phi) + P_T A_{UT}^{\rho_T}(\phi, \phi_s) \right) \right].
\end{aligned}
\qquad (4)
$$

3 Extraction of the TTSA

The data were accumulated with the HERMES forward spectrometer during the running period 2002-2005. The 27.6 GeV positron (electron) beam was scattered off a transversely polarized hydrogen target with an average polarization of 0.72. Events with exactly one positron (electron) and two oppositely charged hadron tracks were selected. Exclusive ρ^0

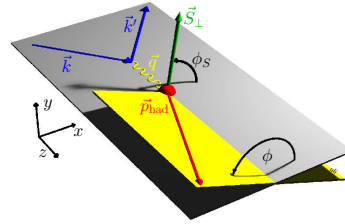[a]For simplicity hereafter x_B, Q^2 and t' are omitted.

events were identified by requiring $\Delta E = \frac{M_X^2 - M_p^2}{2M_p} < 0.6$ GeV, where M_x^2 is the missing mass squared and M_p is the proton mass. Due to the experimental resolution and limited acceptance, semi-inclusive pion production can contribute to the exclusive sample; this is the primary background. It is well reproduced by the PYTHIA simulation and is estimated to be of the order of 10%.

The TTSA asymmetry is extracted by using the unbinned maximum likelihood method where all the moments [7] of $A_{UT}(\phi, \phi_s)$, $A_{UT}^{\rho_L}(\phi, \phi_s)$ and $A_{UT}^{\rho_L}(\phi, \phi_s)$ (Eqs. 3, 4) are fitted simultaneously. In this analysis, the angular distributions $\widehat{W}_{UU}$ and the asymmetries $A_{UU}(\phi)$ of ρ^0, ρ_L^0 and ρ_T^0 meson productions are defined by unpolarized spin density matrix elements (SDMEs) [8] previously measured by HERMES [9].

4 Results

The only TTSA moment of ρ^0s produced from longitudinal photons that is related to the GPDs H and E, is the $\sin(\phi - \phi_s)$ moment. In Figure 2 the $A_{UT}^{\sin(\phi-\phi_s)}$ moment of the TTSA is presented. The panels show from left to right the integrated value and the Q^2, x_B and t' dependences of the asymmetry. For the x_B and t' dependences, Q^2 is required to be above 1 GeV^2. The upper panels represent the ρ^0 total asymmetries, while the middle and the lower panels represent the longitudinal ρ_L^0 and transverse ρ_T^0 separated asymmetries, respectively. The error bars represent the statistical uncertainties only, while the yellow bands indicate the systematic uncertainties due to the target polarization, the background subtraction procedure, the uncertainty resulting from the the unpolarized SDMEs measurement as well as the influence of the beam polarization on the final result.
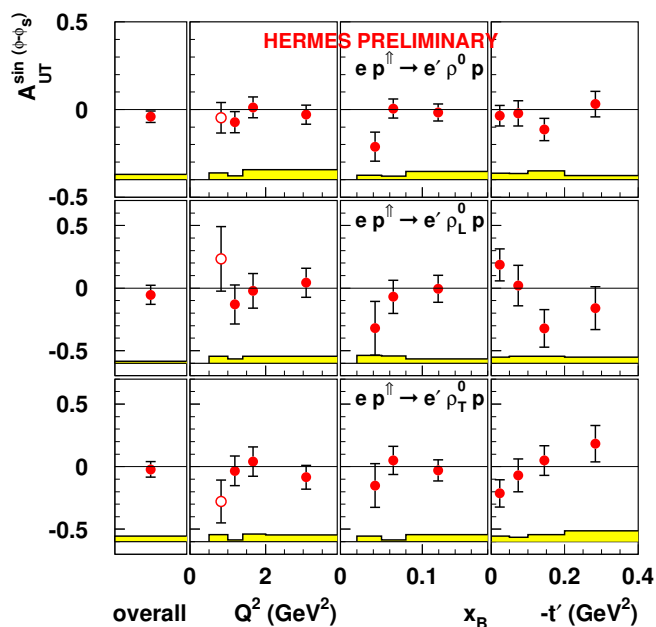

Figure 2: The integrated value, Q^2, x_B and t' dependences of the $A_{UT}^{\sin(\phi-\phi_s)}$ moment of the TTSA of exclusive ρ^0, ρ_L^0 and ρ_T^0 meson productions.

The x_B and t' dependences of the $A_{UT}^{\sin(\phi-\phi_s)}$ moment for longitudinal ρ^0 mesons are compared to the theoretical calculations [10] (see Figure 3). The longitudinal component of $A_{UT}^{\sin(\phi-\phi_s)}$ moment of the asymmetry is related to: $E/H \propto (E_q + E_g)/(H_q + H_g)$, where the E_q, H_q and E_g, H_g represent the quark and gluon GPDs, respectively. Currently no model exists for the gluon GPD E_g. In the present theoretical calculations the gluon GPD E is neglected. However, E_g is not expected to be large compared to the quark GPDs [11]. No large contribution is expected from sea quarks in our x_B range. As GPD E_q is related to
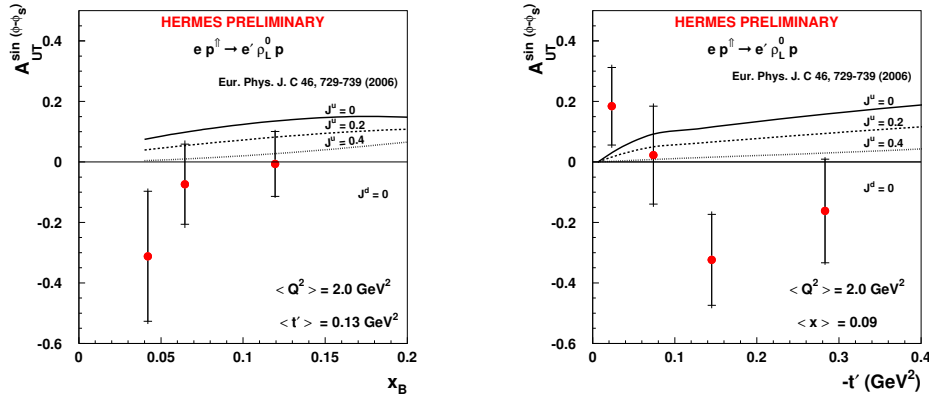
Figure 3: x_B and t' dependences of $A_{UT}^{\sin(\phi-\phi_s)}$ moment of the TTSA of exclusive production of ρ_L^0 mesons compared to the model calculations. The error bars represent the total error.

the total angular momentum J^u and J^d carried by u and d quarks, the $A_{UT}^{\sin(\phi-\phi_s)}$ moment of the asymmetry is sensitive to J^u and J^d. The various curves in Figure 3 represent those calculations for $J^u = 0$, 0.2 and 0.4 and $J^d = 0$. The $J^d = 0$ choice is motivated by the results of recent lattice calculation [12]. The comparison of x_B and t' dependences of the asymmetry with theoretical calculations indicates that the data favors positive J^u values.

5   Conclusion

The $A_{UT}^{\sin(\phi-\phi_s)}$ moment of the TTSA of exclusive ρ^0 meson production is measured on a hydrogen target. The kinematic dependences as well as the integrated value of the asymmetry are presented. In particular, the longitudinal part of the asymmetry is compared to theoretical calculations. The model suggests that the data favors positive J^u values, which is in agreement with deeply virtual Compton scattering results obtained from HERMES data [13].

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