Exclusive Meson Production at HERMES

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ABSTRACT: Hard exclusive electroproduction of vector mesons, such as $\rho^0$, $\Phi$, and $\omega$, is an ideal tool to study production mechanisms and the structure of the nucleon. At the HERMES experiment various cross-sections, asymmetries and spin density matrix elements of these mesons have been measured using different targets. Results from hydrogen and deuteron data are presented and discussed in the context of generalized parton distributions.

KEYWORDS: Nucleon, quark, spin, meson, experiment, detector.

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1. Introduction

Since the discovery of O. Stern and W. Gerlach, "Raumquantizierung der magnetischen Momente in Atomen", the concept of spin is known for approximately hundred years now. Although the formalism of spin with all its consequences and new properties is well integrated in theory, we are far away from fully understanding the origin of spin in the case of composite particles like the nucleon. With polarized Deep Inelastic Scattering (DIS) experiments the helicity dependent Parton Density Functions (PDFs) have been accessed. At the end of 90’s it became clear that the PDF measurements alone can not explain the origin of nucleon spin, as especially angular momentum effects, which seem to have a significant contribution to the nucleon spin, are not accessible this way. The recently developed formalism of Generalized Parton Distributions (GPDs) [1] allows to collect the experimental information from various exclusive reactions measurements to the spin contribution and even to the angular momentum of partons [2] in the nucleon. GPDs actually contain the combined information of PDFs and of form factors (FFs), which are accessible in elastic scattering experiments. The GPD formalism allows to formulate a complete 3-dimensional picture of the nucleon.

Hard exclusive processes can be used to investigate GPDs. By selecting final state particles with different quantum numbers in exclusive meson production, different GPDs can be addressed separately. In particular it was shown [3] that the production of longitudinally aligned $\rho^0$ mesons is sensitive to the GPDs $H$ and $E$, and can be accessed by measuring the Transverse Target Spin Asymmetry (TTSA).

To apply the GPD formalism, we compare data to the GPD model from [4], which uses the CTEQ6 PDFs and predicts the ratio of the longitudinal to the transverse cross section of exclusive $\rho^0$ meson electroproduction. The model also makes predictions of Spin Density Matrix Elements (SDME) and about the hierarchy of certain amplitudes that describe the helicity transfer from the virtual photon to the vector meson.

The gluon orbital angular momentum is yet another unknown component in the nucleon spin puzzle. Under the assumption, that the $\Phi$ meson production is related to a two gluon exchange, Brodsky and Gardner show in [5] how the experimentally accessible Single Spin Asymmetry (SSA) is related to the gluon orbital angular momentum.

In this short note we present four selected recent measurements from HERMES that can lead to a deeper understanding of the spin of the nucleon.
2. Results

The HERMES experiment and spectrometer are described in detail elsewhere [6]. Exclusive Vector Meson (VM) events were identified by detecting the scattered lepton in coincidence with the decay products of VMs: $\rho^0 \rightarrow \pi^+\pi^-$, $\Phi \rightarrow K^+K^-$, $\omega \rightarrow \pi^+\pi^-\pi^0$. To guarantee the exclusivity of the events, cuts on the respective mass windows and constraints on the variable

$$\Delta E = \frac{M_X^2 - M^2}{2M},$$

are applied, where $M_X$ is the missing mass and $M$ is the proton mass. Using the self analyzing power of the vector meson decay it is possible to select the reaction according to final state helicity of the vector meson, i.e. whether it was produced longitudinally or transversely aligned. The TTSA was determined according to

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

where the target polarization $P_T$ is defined with respect to the lepton beam direction, and $\phi$ and $\phi_s$ are the azimuthal angles of the $\rho^0$ meson and the target spin direction around the virtual photon direction (see Fig. 1).

Fig. 2 shows the resulting measurement for the $\sin(\phi - \phi_s)$ component of the $A_{UT}$ asymmetry in case of $\rho^0$ and $\Phi$. The measurements of the $\rho^0$ meson have been compared with a model prediction that is sensitive to the angular momentum $J_u$ of the $u$-quarks [7]. In this model $J_d$ is assumed to be zero. The data favor a value of $J_u = 0.4$ for the $u$-quark total angular momenta. The complete measurements of TTSA and SDME of $\rho^0$ meson on transversely polarized proton target are described in [8]. For the $\Phi$ meson, the kinematically averaged values for the asymmetries in $\sin(\phi - \phi_s)$ and $\sin(\phi + \phi_s)$ are shown in Fig. 2.

Fig. 3 presents HERMES measurement of the $Q^2$ dependence of the longitudinal-to-transverse cross section ratio along with ZEUS data and GPD based theoretical calculations from Ref. [4]. It is clear that the measurement of the whole kinematic domain is important for constraining theoretical model uncertainties. In Fig. 4 the full SDME data set of HERMES is shown for the case of an unpolarized and polarized incoming beam, scattered off an unpolarized proton and deuteron target. Two conclusions can be derived from these measurements: there is a clear similarity of the results for proton and deuteron targets and there is a clear hierarchy in the measured SDME values. The complete set of measurement is described in Ref. [9].
The left panel shows the extracted amplitudes of the \( \sin(\phi - \phi_3) \) component of \( A_{UT} \) for longitudinally (left-top) and transversely (left-bottom) aligned \( \rho^0 \) mesons as a function of \( Q^2 \), \( x_b \) and \( t \). The right panels show the averaged values for \( \Phi \) mesons for the asymmetry in \( \sin(\phi + \phi_5) \) (left) and \( \sin(\phi - \phi_3) \) (right plot). According to prediction [3] the left-top measurement has special importance, because of its sensitivity to the GPD \( E \). The most-right plot presents a rare measurement that can be related to the gluon GPDs [5].

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**References**


Figure 3. $Q^2$ dependence of the longitudinal-to-transverse cross section ratio for exclusive $\rho^0$ production on the proton. $R^{04}$ is shown for ZEUS data (triangles) and $R^{NPE}$ for HERMES data (squares, extracted using natural parity exchange (NPE) amplitudes) and fitted separately. The theoretical model from Ref. [4] with $R_0 = |T_{00}|^2/|T_{11}|^2$ is calculated using helicity amplitudes (dashed line at $W=5$ GeV) The uncertainties arising from the uncertainties of parton distribution functions are shown as a shaded band [4].
Figure 4. The 23 SDMEs extracted from $\rho^0$ data: proton (squares) and deuteron (circles) in the entire HERMES kinematics with $\langle x \rangle = 0.08$, $\langle Q^2 \rangle = 1.95$ GeV$^2$, $\langle -r' \rangle = 0.13$ GeV$^2$. The SDMEs are multiplied by prefactors in order to represent the normalized leading contribution of the corresponding amplitude. SDMEs measured with unpolarized (polarized) beam are displayed in the unshaded (shaded) areas. The vertical dashed line at zero corresponds to SDMEs expected to be zero under the hypothesis of s-channel helicity conservation.