Exclusive meson production at HERMES

Eduard Avetisyan[1] (on behalf of HERMES collaboration)

Deutsches Electronen Synchrotron, 22603 Hamburg, Germany

Abstract The exclusive electroproduction of pseudoscalar and vector mesons was studied with the HERMES spectrometer at the DESY laboratory by scattering 27.6 GeV positron and electron beams off a transversely polarized hydrogen target. The results are compared to calculations based on generalized parton distributions, some of which are sensitive to the contribution of the total angular momentum of the quarks to the proton spin.

Key words exclusive meson production, generalized parton distributions

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1 Introduction

Exclusive electroproduction of mesons can provide new information about the structure of the nucleon because of its relation to generalized parton distributions (GPDs) [1–3]. In Ref. [4] it has been proven that the amplitude for hard exclusive electroproduction of mesons by longitudinal virtual photons can be factorized into a hard-scattering part and two soft parts that depend on the structure of the nucleon and of the produced meson, respectively. In the case of exclusive vector meson production, also the produced meson is longitudinally polarized (in addition to the virtual photon being longitudinal). The amplitude for the soft part (lower blob on Fig. 1) can be expressed in terms of GPDs.

2 Generalized parton distributions

GPDs provide a three-dimensional representation of the structure of the nucleon at the partonic level, correlating the longitudinal momentum fraction of a parton with its transverse spatial coordinates. They are related to the standard parton distribution functions and nucleon form factors [3, 5–7]. At leading twist, meson production is described by four types of GPDs: $H^{q,g}$, $E^{q,g}$, $\widetilde{H}^{q,g}$, and $\widetilde{E}^{q,g}$, where q stands for a quark flavour and g for a gluon. The GPDs are functions of t, x, and ξ, where t is the squared four-momentum transfer to the nucleon, x the average, and ξ half the difference of the longitudinal momentum fractions of the quark or gluon in the initial and final state (c. f. Fig. 1). The quantum numbers of the produced meson determine the sensitivity to the various GPDs. In particular, at leading twist, production of vector mesons is sensitive only to the GPDs H^{q}, E^{q}, H^{g}, and E^{g}, while for the case of pseudoscalar mesons mainly the GPDs $\widetilde{H}^{q,g}$ and $\widetilde{E}^{q,g}$ contribute.

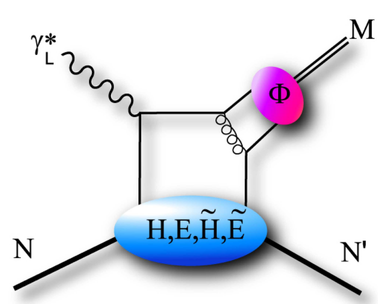

Fig. 1. Hard exclusive meson production diagram.

3 Exclusive vector meson production

The transverse target-spin asymmetry in exclusive electroproduction of longitudinally polarized vector mesons by longitudinal virtual photons is an important observable, because it depends almost linearly on the GPD E [5]. This is in contrast to the unpolarized cross section, where the contribution of E is

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1) E-mail: eduard.avetisyan@desy.de

generally small compared to the contribution of H. At leading twist, the asymmetry is proportional to $\sin(\phi-\phi_{\mathrm{S}})$, where ϕ and ϕ_{S} are the azimuthal angles about the virtual-photon direction of the hadron production plane and the transverse part $\vec{S}_{\mathrm{T}}$ of the target spin, respectively, with respect to the lepton scattering plane (see Fig. 2).

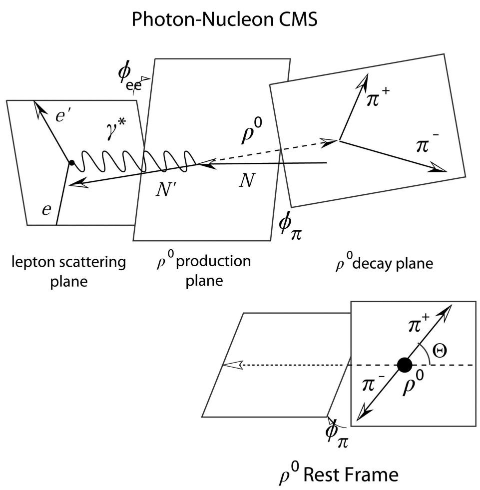

Fig. 2. Upper diagram: the lepton scattering and hadron production planes together with the azimuthal angles ϕ and ϕ_{S}. Lower diagram: ρ^0 decay plane in rest frame with polar ϑ and azimuthal φ angles.

4 Spin density matrix elements

The cross section and asymmetry for exclusive ρ^0 electroproduction $\mathrm{e}+\mathrm{p}\rightarrow\mathrm{e}'+\rho^0+\mathrm{p}'$ can conveniently be described using spin density matrix elements [8–10]. By using the angular distribution of the produced vector meson and of its decay products, described by the polar and azimuthal angles in the vector meson rest frame (c. f. Fig. refphiphis, lower part), one can separate the contributions of mesons with longitudinal and transverse polarization to the measured asymmetries. If s-channel helicity conservation (SCHC) holds, the helicity of the virtual photon is transferred to the produced vector meson. In that case studying the asymmetry for the production of longitudinally polarized vector mesons is tantamount to selecting longitudinal virtual photons. Measurements have shown that SCHC holds reasonably well for exclusive electroproduction of ρ^0 mesons on an unpolarized target at HERMES kinematics [11]. Thus information on the GPD E can be obtained from measurements of the transverse target-spin asymmetry in exclusive ρ^0 electroproduction.

Ultimately, these studies will help to understand the origin of the nucleon spin, because it has been shown [3] that the x-moment in the limit $t\rightarrow 0$ of the sum of the GPDs H^{q} and E^{q} is related to the contribution J^q of the total angular momentum of the quark with flavour q to the nucleon spin. In this contribution, measurements of exclusive ρ^0 electroproduction on transversely polarized protons are presented. Values of the spin density matrix elements (SDMEs) and the transverse target-spin asymmetry for this process were determined.

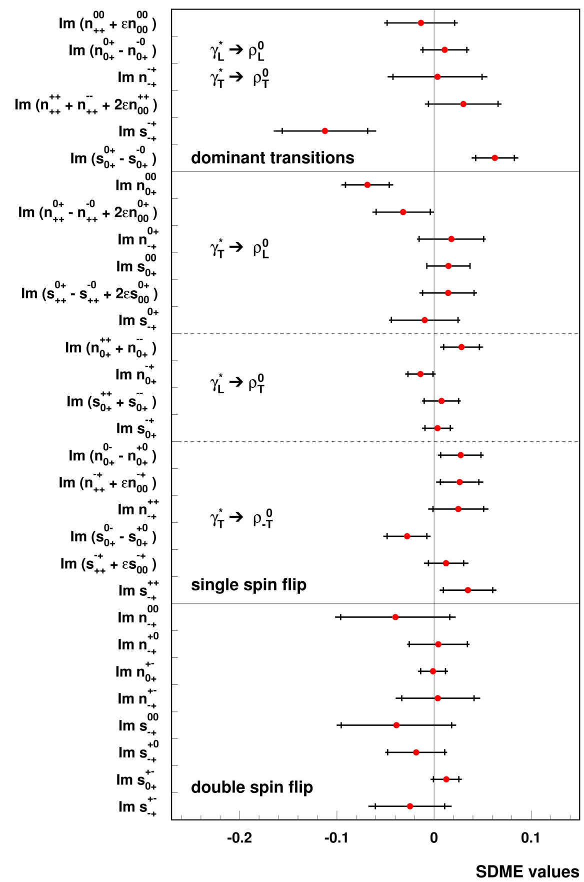

Fig. 3. Transverse-target spin-density matrix elements of exclusive ρ^0 production.

The resulting SDMEs shown in Fig. 3 are mainly consistent with zero within 1.5 σ, where σ represents the total uncertainty in the value of an SDME. Note that these include s-channel helicity conserving SDMEs. It's remarkable that in the unpolarized case such SDMEs were found [11] to be significantly nonzero (0.4 - 0.5). The SDMEs $\mathrm{Im}\big(s^{\,0\,+}_{\,0\,+}-s^{-\,0}_{\,0\,+}\big)$, $\mathrm{Im}\,s^{-+}_{-+}$, and $\mathrm{Im}\,n^{\,0\,0}_{\,0\,+}$ deviate more than 2.5σ from zero. The former two involve the interference between natural (N) and unnatural (U) parity exchange amplitudes [10]. A more complete discussion of the transverse

SDMEs as well as transverse target spin asymmetry amplitudes can be found in Ref. [12].

5 Exclusive pseudoscalar meson production

In the description of hard exclusive electroproduction of pseudoscalarmesons at leading twist, only the two GPDs $\widetilde{H}$ and $\widetilde{E}$ appear. Spin-averaged and spin-dependent cross sections are sensitive to different combinations of these GPDs. It was predicted that for exclusive production of π^+ mesons on transversely polarized protons by longitudinal virtual photons the interference between the pseudovector ($\propto \widetilde{H}$) and pseudoscalar ($\propto \widetilde{E}$) contributions to the cross section leads to a large proton-spin related azimuthal asymmetry [13, 14]. Unlike the spin-averaged cross section, this asymmetry is directly proportional to the sine of the relative phase between $\widetilde{H}$ and $\widetilde{E}$. It was shown that next-to-leading order corrections in the strong-coupling constant α_s cancel in the asymmetry [15, 16]. No GPD based model predictions are available for the production of π^+ mesons by transverse virtual photons as no factorization theorems exist for this case, but also because the leading-twist contribution is expected to be dominant. The result of measurements of the asymmetry amplitude $\sin(\phi-\phi_s)$ performed by HERMES [17] is shown on Fig. 4.

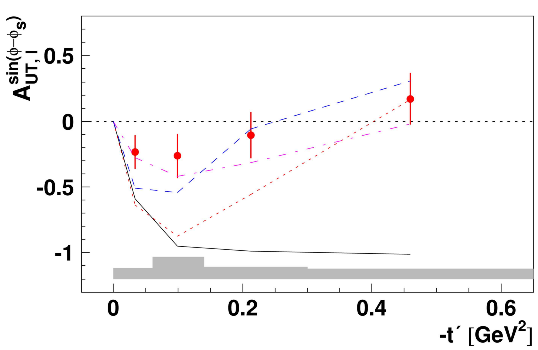

Fig. 4. Data (circles) and model predictions (curves) for the $\sin(\phi-\phi_s)$ Fourier amplitude as a function of t'.

Here, the solid and dotted curves represent the leading-twist, leading-order in α_s calculations of this amplitude for longitudinal virtual photons using two variants of the GPD model of [18]. The modelling of the GPD $\widetilde{E}$ relies here, even at larger values of t, on the dominance of the pion pole $1/(m_\pi^2-t)$ in the pion exchange amplitude, with m_π the pion mass. Then $\widetilde{E}$ is real and positive, and the value of $A_{\mathrm{UT,l}}^{\sin(\phi-\phi_S)}$ is typically predicted to be large and negative, while it must sharply vanish at the kinematic boundary $t'=0$ (see solid curve). The data qualitatively disagree with such a simplified GPD model. A Regge variant of the same GPD model, containing more than just the pion t-channel exchange contribution, results in the dash-dotted curve and is in a better agreement with data. This results suggest that the pure pion-pole contributions in the GPD $\widetilde{E}$ models in leading twist calculations are insufficient to reliably describe the data.

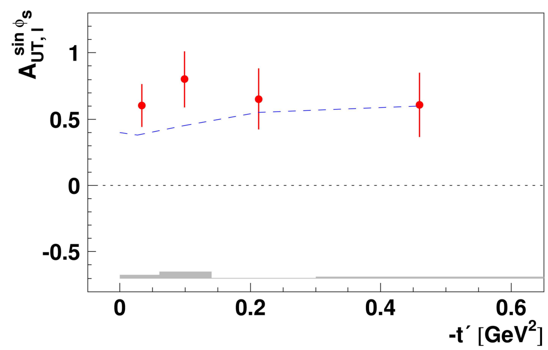

Fig. 5. Data (circles) and model predictions (curves) for the $\sin\phi_s$ Fourier amplitude as a function of t'.

While this dominant Fourier harmonic is compatible with zero within the experimental uncertainties, another asymmetry amplitude, $A_{\mathrm{UT,l}}^{\sin\phi_S}$ is significantly positive and exposes no dependence on $-t'$ (see Fig. 5). This is an indication of significant contribution from the transverse-to-longitudinal helicity transition of the longitudinal virtual photon, involving the higher-twist parton-helicity-flip GPDs H_T and $\widetilde{H}_T$.

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References

1 Müller D. Fortschr. Phys., 1994, **42**: 101
2 Radyushkin A V. Phys. Lett. B, 1996, **380**: 417, Phys. Rev. D, 1997, **56**: 5524
3 JI X. Phys. Rev. Lett., 1997, **78**: 610, Phys. Rev. D, 1997, **55**: 7114
4 Collins J C, Frankfurt L, Strikman M. Phys. Rev., 1997, **56**: 2982
5 Goeke K, Polyakov M V, Vanderhaeghen M. Prog. Part. Nucl. Phys., 2001, **47**: 401
6 Diehl M. Phys. Rep., 2003, **388**: 41
7 Belitsky A V, Radyushkin A V. Phys. Rep., 2005, **418**: 1
8 Schilling K, Wolf G. Nucl. Phys. B, 1973, **61**: 381
9 Fraas H. Ann. Phys., 1974, **87**: 417
10 Diehl M. J. High Energy Phys., JHEP09 (2007) 064
11 Airapetian A et al. EPJC, 2009, **62**: 659–694
12 Airapetian A et al. Phys. Lett. B, 2009, **679**: 100–105
13 Frankfurt L L, Pobylitsa P V, Polyakov M V, Strikman M. Phys. Rev. D, 1999, **60**: 014010
14 Frankfurt L L, Polyakov M V, Strikman M, Vanderhaeghen M. Phys. Rev. Lett., 2000, **84**: 2589
15 Belitsky A V, Müller D. Phys. Lett. B, 2001, **513**: 349
16 Diehl M, Kugler W. Eur. Phys. J. C, 2007, **52**: 933
17 Airapetian A et al. Phys. Lett. B, 2010 **682**: 345–350
18 Bechler Ch, Müller D. arXiv:0906.2571 [hep-ph]