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Exclusive reactions at HERMES

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Summary. — Exclusive scattering processes can, in principle, constrain the parton's angular momentum through its connection to the nucleon Generalized Parton Distributions (GPDs). The HERMES experiment at DESY, Hamburg, collected a wealth of data on hard exclusive leptoproduction of real photons, deeply virtual Compton scattering, or a meson utilizing the HERA polarized electron or positron beams with energy of 25.6 GeV and various polarized or unpolarized internal gas targets. The measured exclusive-photon cross-sections are bilinear in the Compton form factors, the flavor-sums of convolutions of GPDs with hard scattering kernels, while the most informative observables, which could isolate the real or imaginary parts of certain linear combinations of GPDs, are the asymmetries measured with respect to the beam and/or target polarizations. An overview of HERMES results on cross-sections and asymmetries from hard exclusive processes, and their ability to constrain various GPDs are presented.

PACS 13.60.-r – Photon and charged-lepton interactions with hadrons.
PACS 13.60.Le – Meson production.
PACS 13.60.Fz – Elastic and Compton scattering.
PACS 24.85.+p – Quarks, gluons, and QCD in nuclear reactions.

1. – Introduction

The HERMES experiment was designed to study/resolve the so called "Proton Spin Puzzle" originating from the measurement of European Muon Collaboration in 1988 indicating that only a small fraction of the proton spin is carried by quarks. Conceptually, the nucleon spin can be decomposed from the contribution of the spin of its constituents (the quarks and gluons) and their total orbital angular momenta. The HERMES experiment aims to obtain information on all these contributions by measuring either cross section asymmetries from the inclusive and semi-inclusive processes, or cross sections/cross section asymmetries from exclusive processes in lepton-nucleon scattering, respectively.

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Particularly, the possible role of the quark (gluon) orbital angular momentum is addressed by studying hard exclusive processes such as Deeply Virtual Compton Scattering (DVCS). Like the hard exclusive meson production, DVCS can be interpreted in terms of new "objects", the generalized parton distributions (GPDs) [1-3]. The helicity independent GPDs for a nucleon are related to the total orbital angular momentum of a quark (gluon) [3]. Depending on the type of the produced particle in the final state, the exclusive measurements are sensitive to different combinations of GPDs. This paper presents a selection of interesting results in this field obtained by the HERMES Collaboration over the past years.

HERMES used the longitudinally polarized ($P_{B,max} \approx 0.6$) electron or positron beam of 27.6 GeV scattered off longitudinally or transversely polarized hydrogen and longitudinally polarized deuterium targets ($P_T^{H,D} \approx 0.85$) [4] or unpolarized gaseous targets internal to the HERA storage ring. The scattered leptons and produced particles like hadrons of different type or photons were detected by the HERMES spectrometer [5]. The particle identification capability of the experiment was significantly enhanced in 1998 when the threshold Cerenkov detector was upgraded to a dual ring imaging system (RICH). The average lepton identification efficiency was at least 98% with hadron contamination of less than 1%. In the end of 2005, a recoil detector (RD) was installed in the target region of HERMES, the main purpose of which was the detection of the recoil target protons in order to enhance access to hard exclusive processes.

2. – Deeply virtual Compton scattering

Currently, one of the cleanest process that provides a constraint to GPDs is DVCS, *i.e.* hard exclusive leptoproduction of real photons emitted by a struck quark. Experimentally, this process is inevitably mixed with an another process with the same initial and final state, namely Bethe-Heitler (BH), where the final photon is radiated by the incoming or outgoing lepton. Therefore the total cross section of hard leptoproduction of real photons contains an interference term that depends on the charge of the lepton beam.

The individual terms from the cross section of scattering a longitudinally polarized lepton beam off an unpolarized or longitudinally polarized target can be decomposed into Fourier harmonics in azimuthal angle ϕ, which is defined as the angle between the lepton scattering plane and the photon production plane. In a case of a transversely polarized target, the cross section depends in addition on the angle ϕ_S, which is defined as the angle between the lepton scattering plane and the transverse component of the target polarization. Different Fourier components of the squared DVCS (interference) term depend, respectively, on different bilinear (linear) combinations of Compton Form Factors (CFFs), which are convolutions of hard scattering amplitudes with the corresponding GPDs.

At HERMES, the DVCS process is accessed through measurements of cross section asymmetries that appear in the azimuthal distributions of final state photons. Utilizing data collected with longitudinally polarized electron/positron beam of opposite helicities with both target polarization states, it is possible to measure asymmetries with respect to beam charge, beam polarization, target polarization alone and also with respect to different combinations of them.

A set of corresponding asymmetry amplitudes was extracted simultaneously using a maximum likelihood fit. For this purpose, the asymmetries are expanded in Fourier harmonics in azimuthal angles ϕ and ϕ_S, according to Fourier components which appear in the cross sections.

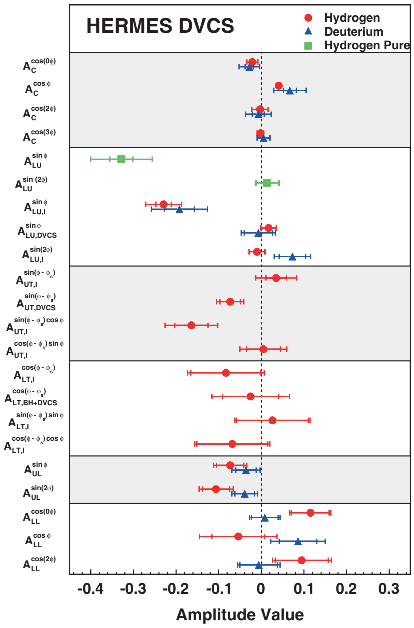

Fig. 1. – Overview of azimuthal asymmetry amplitudes from DVCS measured at the HERMES experiment.

An overview of all extracted azimuthal asymmetry amplitudes for a single kinematic bin covering the entire acceptance of the HERMES apparatus is presented in fig. 1 for both hydrogen and deuterium targets [6-15]. The amplitudes of the beam-helicity and beam-charge asymmetries $A_{LU}^{DVCS}(\phi)$, $A_{LU}^{I}(\phi)$ and $A_C(\phi)$ are presented in the top two panels of fig. 1. Significant non-zero $\cos(\phi)$ and $\sin(\phi)$ amplitudes were observed for beam-charge and beam-helicity asymmetries $A_C(\phi)$ and $A_{LU}^{I}(\phi)$, respectively. At HERMES kinematic conditions, these two amplitudes are sensitive to the real and imaginary parts of CFF $\mathcal{H}$. The results for the $\sin(\phi)$ amplitude of the charge-averaged beam-helicity asymmetry $A_{LU}^{DVCS}(\phi)$ are consistent with zero. In the bottom two panels of fig. 1, the results of single- and double-spin target-spin asymmetries $A_{UL}(\phi)$ and $A_{LL}(\phi)$ are presented both for longitudinally polarized hydrogen and deuterium targets. For the case of the hydrogen target, the leading amplitudes of these asymmetries are sensitive to the imaginary and real parts of CFF $\widetilde{H}$, respectively. Also shown in fig. 1 are the leading amplitudes of single- and double-target-spin asymmetries, measured on the transversely polarized hydrogen target. The amplitude $A_{UT,I}^{\sin(\phi-\phi_S)\cos(\phi)}$, which has significant negative value, is sensitive to the imaginary part of CFF $\mathcal{E}$, while the amplitude $A_{LT,I}^{\sin(\phi-\phi_s)\sin(\phi)}$, which is sensitive to the real part of CFF $\mathcal{E}$, is consistent with zero.

Most of the results for the asymmetry amplitudes from fig. 1 were obtained without recoil particle detection. In this case, the exclusivity of the process was achieved using the missing-mass event selection technique. This method does not allow the separation of the pure DVCS/BH events from those of "associated" processes where the target nucleon excites to a baryonic resonant state, and therefore they remain as part of the signal. The associated background contributes about 12% in the measured exclusive sample for hydrogen data. For the data collected at HERMES after the installation of the recoil detector, it became possible to exclude the contribution of the above mentioned

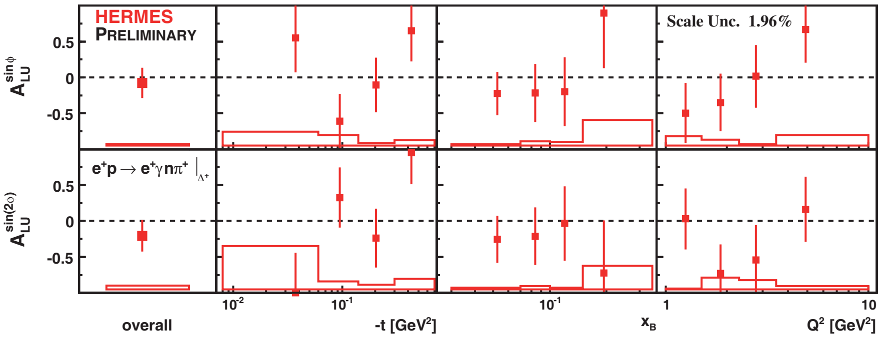

Fig. 2. – The beam-helicity asymmetry amplitudes associated with the process $e^+p \to e^+\Delta^+\gamma \to e^+n\pi^+\gamma$.

associated background and achieve a purity of the DVCS/BH process of more than 99%. The results of single-charge (positron) beam-helicity asymmetry amplitudes $A_{LU}^{\sin(n\phi)}$ from the pure exclusive event sample obtained on a hydrogen target with detection of all particles in the final state are also shown in the second panel from the top of fig. 1.

Detection of recoiling particles also made it possible to estimate the contributions from "associated" processes. The asymmetry amplitudes in this case are extracted from "nucleon-excited baryon-enriched" data sample using the kinematic fitting method for the selection of a given process. As an example, the preliminary results of $\sin(n\phi)$ amplitudes of the beam-helicity asymmetry for the $e^+p \to e^+\Delta^+\gamma \to e^+n\pi^+\gamma$ decay channel are presented in fig. 2. The "overall" results in the left column correspond to the entire HERMES kinematic acceptance. The dependence on kinematic variables t, x_B and Q^2, the squared momentum transfer to the nucleon, Bjorken variable and negative square of the four-momentum of the virtual photon are also shown in fig. 2. The amplitudes of both asymmetries are compatible with zero.

Note that HERMES also has published the beam-charge and beam-helicity asymmetry amplitudes in DVCS measured on selected nuclear targets [16].

3. – Hard exclusive meson production

The study of hard exclusive meson leptoproduction processes offers another possibility of constraining GPDs. In the case of exclusive pseudo-scalar meson production, the experimental observables, such as the cross section or the cross section asymmetries, are sensitive to polarized GPDs $\tilde{H}$ and $\tilde{E}$. In the case of exclusive vector meson production, the unpolarized GPDs H and E can be accessed. and as the interaction of $q\bar{q}$ pair with the nucleon can proceed via quark-antiquark or two-gluon exchanges mechanisms, it provides information also about gluon GPDs.

The upper panel of fig. 3 shows the differential cross section for exclusive π^+ production by virtual photons as a function of $-t'$ for four Q^2 bins [17]. The curves in fig. 3 correspond to two alternative approaches: the dashed-dotted (solid) lines show the leading-order (including power correction due to the intrinsic transverse momentum of partons) calculations of the longitudinal part computed using the GPD model of ref. [18]. The dashed (dotted) lines are the total and longitudinal parts of the cross section computed using Regge phenomenology [19]. The left bottom plot shows the Q^2 dependence of the cross section integrated over t' for three x_B bins. The Regge formalism provides a good description of the data, while, if power corrections are included, the GPD model is

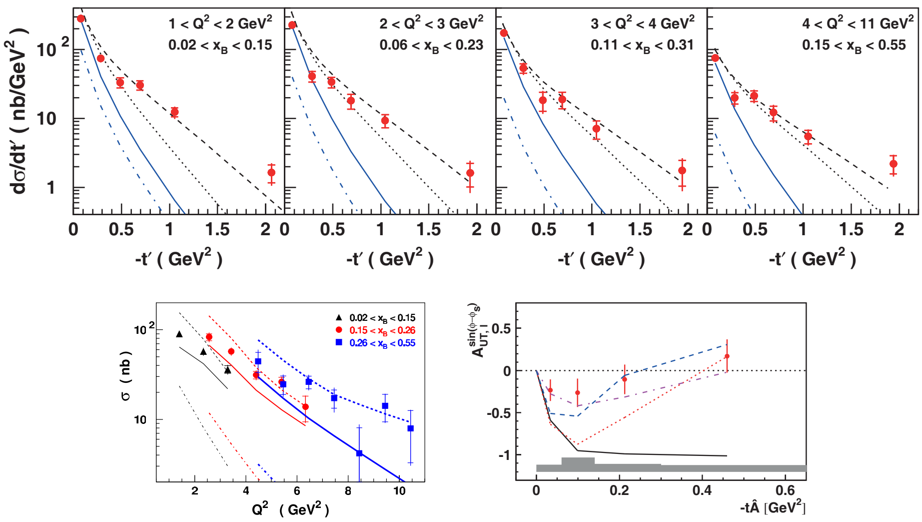

Fig. 3. – Upper panel: the differential cross section for exclusive π^+ production by virtual photons as a function of $-t'$ for four Q^2 bins. Bottom left: the Q^2 dependence of the cross section integrated over t' for three x_B bins. Bottom right: the transverse target-spin asymmetry amplitude $A_{UT,I}^{\sin(\phi-\phi_S)}$ *vs.* $-t'$ (see ref. [20] for theoretical calculations).

in fair agreement with the magnitude of the data at low values of $-t'$. The bottom right plot of fig. 3 shows the measured transverse target-spin asymmetry amplitude $A_{UT,I}^{\sin(\phi-\phi_S)}$ in exclusive π^+ production as a function of $-t'$ [20]. This amplitude was found to be consistent with zero, suggesting a possible dominance of GPD $\tilde{E}$ over $\tilde{H}$. The rest of the amplitudes of the target-spin asymmetry are compatible with zero except $A_{UT,I}^{\sin(\phi_S)}$ indicating a significant contribution from the transverse-to-longitudinal helicity transition of the virtual photon [21].

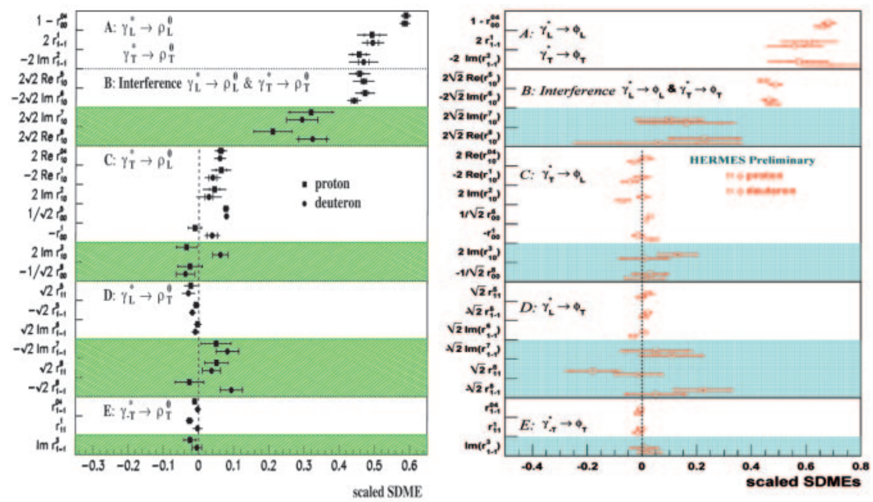

Fig. 4. – The SDMEs for ρ^0 and ϕ meson electroproduction.

The Spin Density Matrix Elements (SDMEs) measured in exclusive ρ^0 [20] and ϕ meson productions on hydrogen and deuterium targets are presented in fig. 4. The different spin transitions between virtual photon and vector meson are grouped into different classes. The unshaded (shaded) areas correspond to the SDMEs measured with unpolarized (polarized) lepton beam. The measured SDMEs of classes A and B have significant non-zero values for both ρ^0 and ϕ mesons with an average difference of 10 to 20% between them. Significant non-zero values of SDMEs of class C are observed for ρ^0 meson indicating a production mechanism that does not conserve s-channel helicity. The results for both ρ^0 and ϕ meson SDMEs of all other classes are consistent with zero except the polarized ρ^0 SDMEs showing slightly positive values for class D.

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REFERENCES

[1] Muller D. *et al.*, *Fortsch. Phys.*, **42** (1994) 101.
[2] Radyushkin A. V., *Phys. Lett. B*, **380** (1996) 417.
[3] Ji X., *Phys. Rev. Lett.*, **78** (1997) 610.
[4] Airapetian A. *et al.* (HERMES Collaboration), *Nucl. Instrum. Methods A*, **540** (2005) 68.
[5] Airapetian A. *et al.* (HERMES Collaboration), *Nucl. Instrum. Methods A*, **417** (1998) 230.
[6] Airapetian A. *et al.* (HERMES Collaboration), *Phys. Rev. Lett.*, **87** (2001) 182001.
[7] Airapetian A. *et al.* (HERMES Collaboration), *Phys. Rev. D*, **75** (2007) 011103.
[8] Airapetian A. *et al.* (HERMES Collaboration), *JHEP*, **06** (2008) 066.
[9] Airapetian A. *et al.* (HERMES Collaboration), *JHEP*, **11** (2009) 083.
[10] Airapetian A. *et al.* (HERMES Collaboration), *JHEP*, **06** (2010) 019.
[11] Airapetian A. *et al.* (HERMES Collaboration), *Phys. Lett. B*, **704** (2011) 15.
[12] Airapetian A. *et al.* (HERMES Collaboration), *JHEP*, **07** (2012) 032.
[13] Airapetian A. *et al.* (HERMES Collaboration), *JHEP*, **10** (2012) 042.
[14] Airapetian A. *et al.* (HERMES Collaboration), *Nucl. Phys. B*, **829** (2010) 1.
[15] Airapetian A. *et al.* (HERMES Collaboration), *Nucl. Phys. B*, **842** (2011) 265.
[16] Airapetian A. *et al.* (HERMES Collaboration), *Phys. Rev. C*, **81** (2010) 035202.
[17] Airapetian A. *et al.* (HERMES Collaboration), *Phys. Lett. B*, **659** (2008) 486.
[18] Vanderhaeghen M., Guichon P. A. M. and Guidal M., *Phys. Rev. D*, **60** (1999) 094017.
[19] Laget J. M., *Phys. Rev. D*, **70** (2004) 054023.
[20] Airapetian A. *et al.* (HERMES Collaboration), *Phys. Lett. B*, **682** (2010) 345.
[21] Goloskokhov S. V. and Kroll P., *Eur. Phys. J. C*, **65** (2010) 137.
[22] Airapetian A. *et al.* (HERMES Collaboration), *Eur. Phys. J. C*, **62** (2009) 659.