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THE HERMES DVCS ROADMAP

F. ELLINGHAUS
(ON BEHALF OF THE HERMES COLLABORATION)
University of Colorado, Boulder, Colorado 80309-0390, USA
E-mail: Frank.Ellinghaus@desy.de

The measurement of azimuthal asymmetries in the exclusive electroproduction of real photons provides the theoretically cleanest access to generalized parton distributions. The asymmetries are attributed to the interference between deeply–virtual Compton scattering and Bethe–Heitler processes. Performed measurements on the proton are briefly reviewed and projections for the last three years of the HERMES data taking are given. Comparisons of the projections to model calculations focus on the question how and if at all HERMES will be able to access the total angular momentum of quarks in the nucleon.

1 Introduction

Similar to the case of inclusive and semi-inclusive DIS, where the nucleon structure is described using **P**arton **D**istribution **F**unctions (PDFs), hard exclusive reactions can be expressed in terms of **G**eneralized **P**arton **D**istributions (GPDs). The ordinary PDFs and nucleon form factors turn out to be the limiting cases and moments of GPDs, respectively [1]. Although GPDs have been known for a while [2,3], strong interest was created only after the finding by Ji [1] that the GPDs offer for the first time a possibility to determine the total angular momentum carried by the quarks in the nucleon.

2 Deeply–Virtual Compton Scattering

The **D**eeply–**V**irtual **C**ompton **S**cattering (DVCS) process, i.e., the hard exclusive leptoproduction of real photons, appears to provide the theoretically cleanest access to GPDs. DVCS amplitudes can be measured through the interference between the DVCS and **B**ethe–**H**eitler (BH) processes, in which the photon is radiated from a parton in the former and from the electron in the latter process. Both processes have an identical final state, i.e., they are indistinguishable and thus their amplitudes (τ_{DVCS}, τ_{BH}) add coherently. For an unpolarized proton target, the cross section for the exclusive leptoproduction of photons reads [4]

$$\frac{d\sigma}{dx_B\, dQ^2\, d|t|\, d\phi} = x_B\, y^2 \frac{|\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \overbrace{\tau_{DVCS}\,\tau^*_{BH} + \tau^*_{DVCS}\,\tau_{BH}}^{I}}{32\,(2\pi)^4\, Q^4\, \sqrt{1+4\,x_B^2\, M_p^2/Q^2}}, \qquad (1)$$

where x_B represents the Bjorken scaling variable, $-Q^2$ the virtual–photon four–momentum squared, y the fraction of the incident lepton energy carried by the virtual photon and t and M_p are the Mandelstam variable and the proton mass, respectively. The azimuthal angle ϕ is defined as the angle between the lepton scattering plane, i.e., the plane defined by the incoming and the outgoing lepton, and the photon production plane made up correspondingly by the virtual and the real photon. At leading twist, the interference term I is given by [4]

$$I = \pm \frac{4\sqrt{2}\, m\, e^6}{t\, Q\, x_B} \frac{1}{\sqrt{1-x_B}} \times [\cos\phi \frac{1}{\sqrt{\epsilon(\epsilon-1)}} \Re M^{1,1} - P_l \sin\phi \sqrt{\frac{1+\epsilon}{\epsilon}} \Im M^{1,1}], \quad (2)$$

where +(-) denotes a negatively (positively) charged lepton beam with polarization P_l, e represents the electron charge and ϵ is the ratio of longitudinal to transverse initial photons in the DVCS process. Measuring the ϕ–dependence of a cross section asymmetry with respect to the charge (spin) of the lepton beam provides information about the real (imaginary) part of the DVCS amplitude. The DVCS amplitude [5]

$$M^{1,1} = F_1\, H_1 + \frac{x_B}{2-x_B}(F_1 + F_2)\, \tilde{H}_1 - \frac{t}{4M^2} F_2\, E_1 \quad (3)$$

is given by a linear combination of the so–called Compton form factors (CFFs) H_1, $\tilde{H}_1$ and E_1, together with the Dirac and Pauli form factors F_1 and F_2, respectively. The CFFs are convolutions of the respective twist–2 GPD H, $\tilde{H}$ or E and of the hard scattering amplitude, the latter being calculated up to NLO in pQCD.

3 Data Selection

Data on unpolarized and spin–averaged polarized hydrogen targets have been accumulated with the HERMES spectrometer [6] at the HERA electron/positron–proton collider at DESY which offers longitudinally polarized 27.6 GeV electron and positron beams. Events were selected if they contained exactly one photon and one charged track, identified as the scattered lepton. The kinematic requirements imposed on the scattered lepton were Q^2 >1 GeV^2, $W^2 > 4$ GeV^2 and $\nu < 23$ GeV, where W denotes the photon–nucleon invariant mass and ν is the virtual–photon energy. The photon was identified by detecting an energy deposition in the preshower scintillator and in the calorimeter without an associated charged track. The polar angle $\theta_{\gamma^*\gamma}$ between the virtual and the real photon was required to be within 15 to 70 mrad in the earlier analysis and between 2 and 70 mrad in the later analysis. The decreased lower limit is due to an improved photon position reconstruction algorithm. The recoiling proton was not detected. Exclusive events are identified by the fact that the missing mass of the reaction $ep \to e\gamma X$ corresponds to the proton mass. Due to the finite energy resolution the exclusive sample is defined as $-1.5 < M_x < 1.7$ GeV as determined from signal–to–background studies using a Monte-Carlo simulation.

4 The GPD H

The beam–charge (BCA) and the beam–spin asymmetry (BSA) as a function of ϕ are calculated as

$$A_C(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}, \qquad A_{LU}(\phi) = \frac{1}{<|P_l|>} \frac{\overrightarrow{N}(\phi) - \overleftarrow{N}(\phi)}{\overrightarrow{N}(\phi) + \overleftarrow{N}(\phi)}, \quad (4)$$

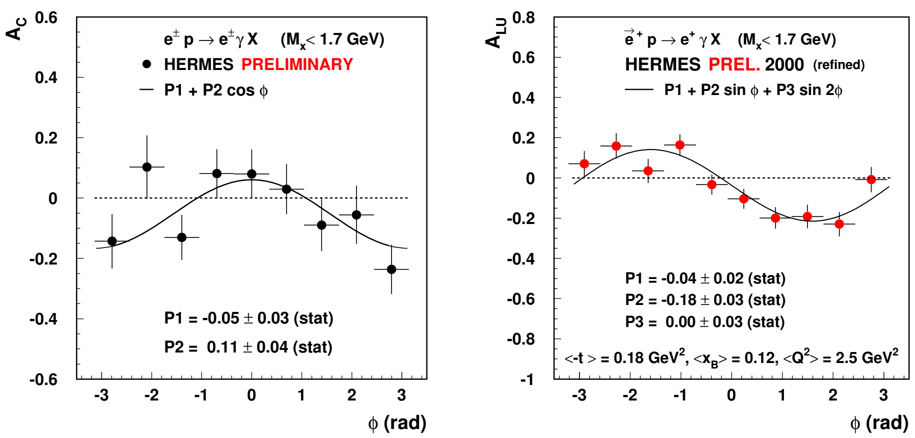

Figure 1. Beam–charge asymmetry A_C [7] and beam–spin asymmetry A_{LU} [8] for the hard electroproduction of photons off the proton as a function of the azimuthal angle ϕ for the exclusive sample. The solid curves show the results of the indicated fits with the values given in the plots.

with the normalized yields N^+ (N^-) or $\overrightarrow{N}$ ($\overleftarrow{N}$) using a positron (electron) beam or a beam with positive (negative) helicity, respectively. The asymmetries on the proton as a function of ϕ are shown in Fig. 1 for the exclusive sample. Similar results for the BSA have also been obtained using heavier targets (D, Ne) [8]. The results from the indicated fits in Fig. 1 indeed show the expected $\cos\phi$ ($\sin\phi$) dependence for the BCA (BSA). These results together with the ones on the BSA from the 96/97 data and from the CLAS collaboration are shown in Fig. 2 at their average kinematic values. Note that the smaller average $-t$–value of the 2000 data when compared to the result from the 96/97 data is due to the fact that events with small angles $\theta_{\gamma^*\gamma}$ have been included in the later analysis as described above. The model calculations shown in the same plot are based on a GPD model described in references [11,12]. Note that at small values of x_B (t) the contribution from the CFFs $\tilde{H}_1$ (E_1) to the amplitude $M^{1,1}$ is suppressed (see Eqn. 3), i.e., the main contribution to the asymmetries in the kinematic region of HERMES originates from the CFF H_1 and thus it originates from the GPD H. Consequently the model parameters in the underlying code [13] were varied only for the GPD H in order to calculate the asymmetries at the average kinematics of every bin. The model parameters (see table) differ with respect to including or neglecting the so–called D–term [14] in the GPD model and whether the t–dependence of the GPD H is calculated in either the simplest ansatz where the t–dependence factorizes from the t–independent part or in the Regge–motivated ansatz. In addition, the parameters b_{val} and b_{sea} in the profile function have been varied. Especially in the case of the BCA it becomes apparent that a measurement of the kinematic dependence is mandatory in order to be able to distinguish between the models since at the average kinematic values of HERMES the models B and C are almost indistinguishable while they show

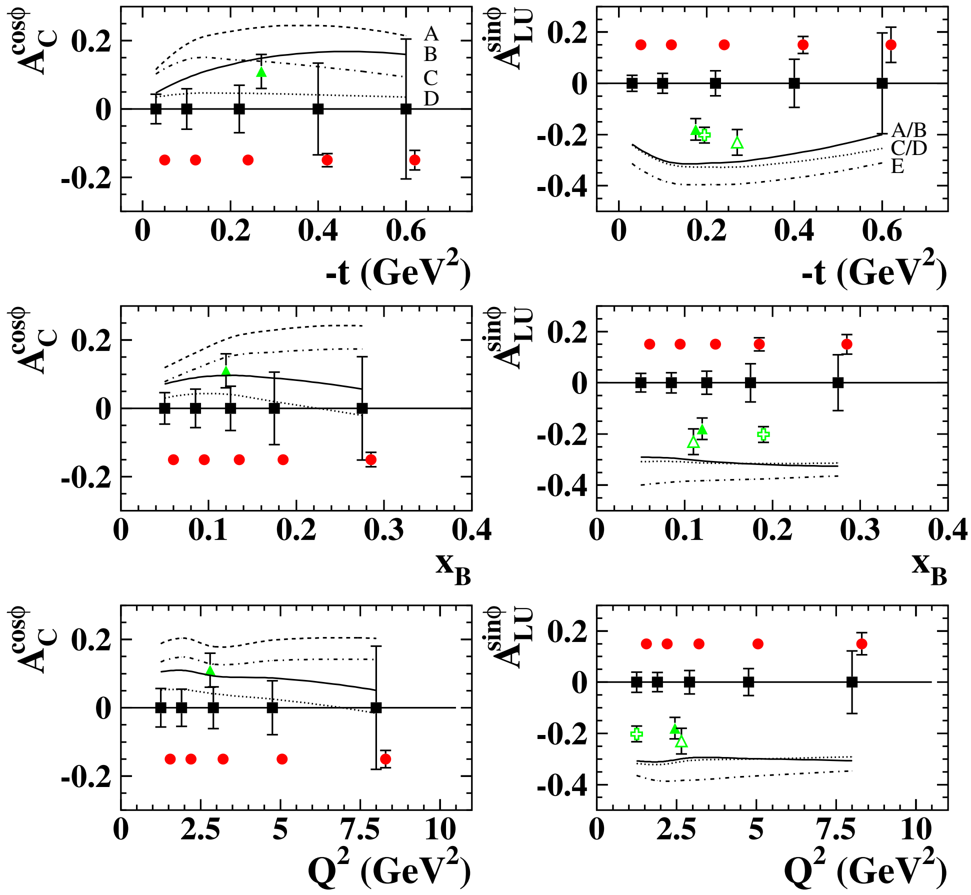

Figure 2. The $\cos\phi$ dependence of the BCA (left panels, closed triangles) from HERMES [7] and the $\sin\phi$ dependence of the BSA (right panels) from the 96/97 HERMES data [9] (open triangles), from the 2000 HERMES data [8] (closed triangles), and from CLAS [10] (open crosses) at their average kinematic values. Statistical and systematic errors are added in quadrature. The parameter sets for the GPD models are given in the table. The predictions from the models A, B, C and D are used for comparison with the BCA (left panels). The BSA is insensitive to the D-term contribution and thus yields the same result for the models A/B and C/D (right panels). See text for explanation on the projections (squares,circles).

Model	D–Term	b_{val}	b_{sea}	Ansatz t–dependence
A	Yes	1	∞	Regge
B	No	1	∞	Regge
C	Yes	1	∞	factorized
D	No	1	∞	factorized
E	Yes/No	1	1	factorized

a clearly different behavior as a function of t. The extraction of the kinematic dependences of the asymmetries for the HERA Run I data on hydrogen (1996-2000) is almost completed, the projected statistical precision is shown in the same figure (squares). The additional statistics expected from a dedicated running on unpolarized hydrogen in the final two years of HERA (summer 2005 – summer 2007) is also displayed (circles), provided that about 1 $fb^{-}1$ with each beam charge can be collected. A recoil detector, presently under construction, will help to more clearly identify exclusive reactions and thus to reduce the underlying background to less than 1%. It can be concluded that the upcoming HERMES data should be able to put serious constraints on the GPD H.

5 The GPD E

As described above HERMES will be able to provide sufficient data to essentially fix the model parameters for the GPD H. It is natural to ask to what extend the GPD E can be accessed which is the other important GPD necessary in order to determine J_q, the total orbital angular momentum of the quarks in the nucleon. While for an unpolarized target the contribution from the GPD E is suppressed with respect to H (see Eqn. 3), this is different for transverse target polarization [5,15]. In the HERMES laboratory system a left–right asymmetry $A_{UT,1}$ and a top–bottom asymmetry $A_{UT,2}$ have been identified [16] which give access to the GPD combinations $F_2H - F_1E$ and $F_2\tilde{H} + (x_B/2)F_1(E - \tilde{E})$, respectively. HERMES is presently running with a transversely polarized target and expects to collect about 6 million DIS events until summer 2005. A projection based on 4 million DIS events is shown in Fig. 3. For the model calculations it is assumed that the contribution of J_d is zero due to u–quark dominance and that the other model parameters are fixed from the measurements on unpolarized hydrogen as described above. As expected, the asymmetry $A_{UT,2}$ is almost insensitive to variations on the input values for the GPD model for E. Small effects can only be seen for large x_B or correspondingly large Q^2. The measurement of $A_{UT,1}$ on the other hand might give a glimpse on J_u, especially since the models show similar kinematic dependences and thus the data can be combined into one point.

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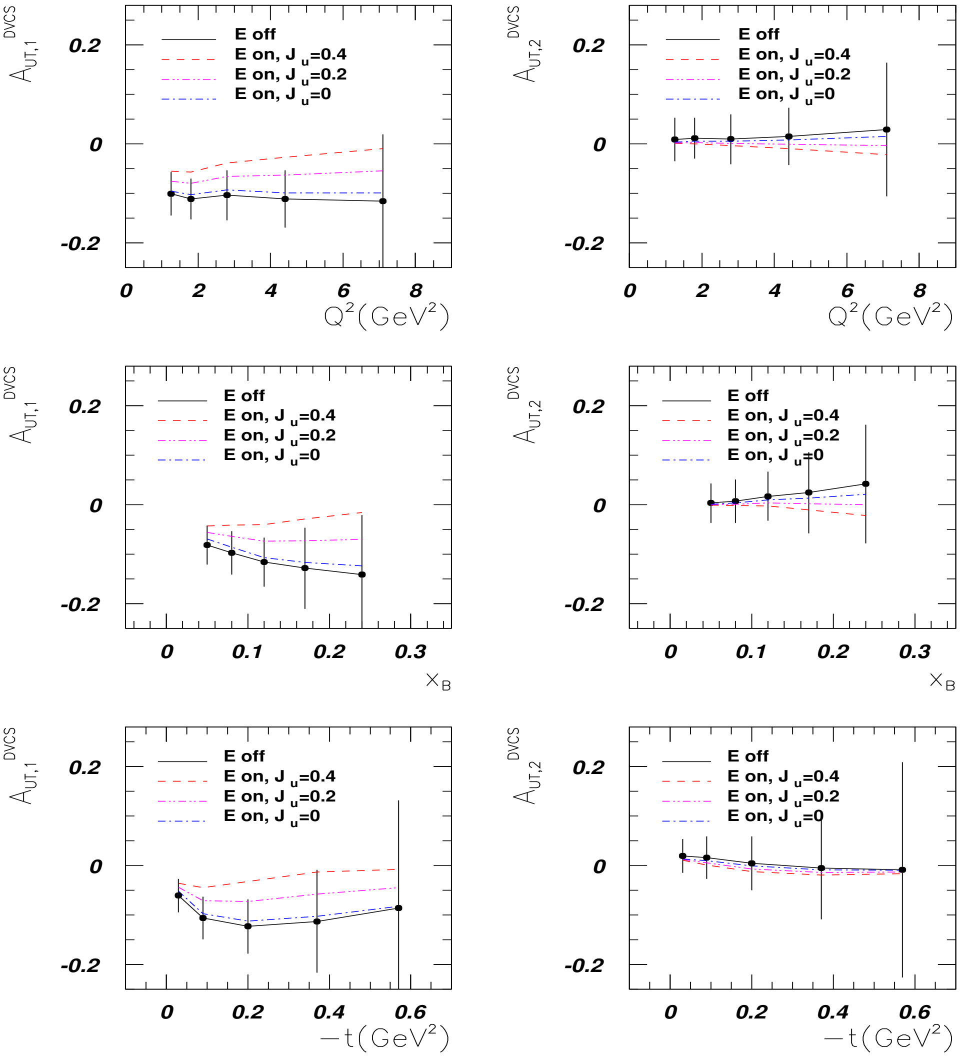

Figure 3. Projections [16] for the left–right asymmetry $A_{UT,1}$ and the top–bottom asymmetry $A_{UT,2}$ based on a sample of 4 million DIS collected on the transverse hydrogen target. The model calculations are done using the factorized t-ansatz, $b_{val} = 1$, $b_{sea} \to \infty$ and $J_d = 0$.

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