Experimental Overview of DVCS Results from HERMES

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The HERMES experiment at DESY, Hamburg, collected a rich data set for the analysis of Deeply Virtual Compton Scattering (DVCS) utilizing the HERA polarized electron or positron beams with an energy of 27.6 GeV and longitudinally and transversely polarized or unpolarized gas targets (H, D or heavier nuclei). The azimuthal asymmetries measured in the DVCS process allow access to the imaginary and/or real part of certain combinations of generalized parton distributions.

1 Introduction

Hard exclusive electroproduction of real photons on nucleons, Deeply Virtual Compton Scattering (DVCS), is one of the theoretically cleanest ways to access Generalized Parton Distributions (GPDs). The theoretical framework of GPDs incorporates knowledge about form factors and parton distribution functions. GPDs depend on three kinematic variables: the squared four-momentum transfer $t$ to the nucleon and $x$ and $\xi$, which represent respectively the average and half the difference of the longitudinal momentum fractions carried by the probed parton in initial and final states. For the proton, there are four twist-2 GPDs per quark flavor: $H_q$, $E_q$, $\tilde{H}_q$ and $\tilde{E}_q$.

DVCS is experimentally indistinguishable from the electromagnetic Bethe-Heitler (BH) process because of the same final state. The real photon is radiated from the struck quark in DVCS or from the initial or scattered lepton in BH. The cross-section of the exclusive photoproduction process can be written in the following form [1]:

$$
\frac{d\sigma}{dxdQ^2dtd\phi} = \frac{\alpha^3 x_B y}{16\pi^2 Q^2 c^3} \frac{2 \pi y |T_{DVCS}|^2 + |T_{BH}|^2 + I}{\sqrt{1 + 4x_B^2 M_N^2 / Q^2}},
$$

where $T_{DVCS}$ ($T_{BH}$) is the DVCS (BH) amplitude, $I$ is the interference term, $x_B$ is the Bjorken scaling variable and $-Q^2$ is the squared four-momentum transferred by the virtual photon. The amplitude of the BH process can be precisely calculated from measured elastic form factors of the nucleon. The BH process dominates at HERMES kinematics. However, the kinematic dependences of the cross section terms generate a set of azimuthal asymmetries which depend on the azimuthal angle $\phi$ between the real-photon production plane and the lepton scattering plane.

2 Measured asymmetries

The cross section for a longitudinally polarized lepton beam scattered off an unpolarized proton target $\sigma_{LU}$ can be related to the unpolarized cross section $\sigma_{UU}$ by

$$
\sigma_{LU}(\phi; P_B, C_B) = \sigma_{UU}(\phi) \cdot \left[ 1 + P_B A_{LU}^{DVCS}(\phi) + C_B P_B A_{LU}^I(\phi) + C_B A_C(\phi) \right],
$$

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where $A_{LU}^I$ ($A_{LU}^{DVCS}$) is the charge (in)dependent beam-helicity asymmetry (BSA) and $A_C$ is
the beam charge asymmetry (BCA), $C_B(P_B)$ denotes the beam charge (polarization). In the
analysis effective asymmetry amplitudes are extracted, which include $\phi$ dependencies from
the BH propagators and the unpolarized cross section. Each asymmetry can be expanded
in a Fourier series in $\phi$:

$$A_{LU}^I(\phi) = \sum_{n=1}^{2} A_{LU,1}^{\sin(n\phi)} \sin(n\phi) + \sum_{n=0}^{1} A_{LU,1}^{\cos(n\phi)} \cos(n\phi), \quad (3)$$

$$A_{LU}^{DVCS}(\phi) = \sum_{n=1}^{2} A_{LU,DVCS,1}^{\sin(n\phi)} \sin(n\phi) + \sum_{n=0}^{1} A_{LU,DVCS,1}^{\cos(n\phi)} \cos(n\phi), \quad (4)$$

$$A_C(\phi) = \sum_{n=0}^{3} A_C^{\cos(n\phi)} \cos(n\phi) + A_C^{\sin\phi} \sin\phi. \quad (5)$$

By combining the data taken with different beam charges and helicities, the amplitudes
were fit simultaneously using a Maximum Likelihood method described in detail in [2]. In
the case of unpolarized beam and transversely polarized target, the transverse target-spin
azimuthal asymmetry (TTSA) can be measured, which in addition to $\phi$ also depends on the
angle $\phi_S$ between the lepton scattering plane and the direction of the target polarization
vector.

3 Experiment and data analysis

beams of the HERA storage ring at DESY together with longitudinally and transversely
polarized or unpolarized gas targets (H, D or heavier nuclei). Exclusive events were selected
requiring the detection of exactly one scattered lepton and of exactly one photon. In addi-
tion, as the recoiling proton has not been detected, the missing mass was required to match
the proton mass within the resolution of the spectrometer, which defines the “exclusive re-
region”. Without recoil proton detection it is not possible to separate the elastic DVCS/BH
events from the “associated” process, where the nucleon in the final state is excited to a res-
onant state. Within the exclusive region, its contribution is estimated from a Monte Carlo
simulation to be about 12%, which is taken as part of the signal. The main background
contribution of about 3% is originating from semi-inclusive $\pi^0$ production and is corrected
for. The contribution from exclusive $\pi^0$ production is estimated to be less than 0.5%. The
systematic uncertainties are obtained from a Monte Carlo simulation estimating the effects
of limited acceptance, smearing, finite bin width and alignment of the detectors with respect
to the beam. Other sources are background contributions and a shift of the position of the
exclusive missing mass peak between the data taken with different beam charges.

4 Results

In Figures 1 and 2 results obtained with the hydrogen target are shown [4]. The first four
rows of Fig. 1 represent different cosine amplitudes of the BCA, whereas the last row displays
the fractional contributions of the associated BH process. In the first column the integrated
result is shown, in the other columns the amplitudes are binned in $-t$, $x_B$ or $Q^2$. The error
bars show the statistical and the bands the systematic uncertainties. The magnitudes of the first two cosine moments $A_C \cos \phi$ and $A_C \cos 2 \phi$ increase with increasing $-t$, while having opposite signs in agreement with theoretical expectations. In HERMES kinematics, both relate to the real part of the GPD $H$, but the constant term is suppressed relative to the first moment. The second cosine moment appears in twist-3 approximation and is found to be compatible with zero like the third cosine moment, which is related to gluonic GPDs. The first sine moment $A_s \sin \phi$ is large and negative in the covered kinematics (see Fig. 2). This amplitude relates to the imaginary part of the GPD $H$. Also shown in the figures are GPD model calculations based on the framework of double distributions [5]. The model includes a Regge-inspired $t$-ansatz and a factorized $t$-ansatz. The BCA amplitudes favor the double-distribution model with a Regge-inspired $t$-dependence, if the D-term is neglected. Both model calculations fail to describe the data except for small $-t$. The charge-independent BSA moments are found to be compatible with zero. Results obtained with a deuteron target (not shown) are compatible for almost all amplitudes.

For data taken with the transversely polarized target, the beam charge asymmetry $A_C(\phi)$ and the TTSAs $A_{UT}^{DVCS}(\phi)$ and $A_{UT}^{IUT}(\phi)$ from DVCS and interference term, respectively, have been extracted simultaneously. By comparing GPD model calculations [5] with the measured BCA and TTSAs, a model-dependent constraint on the total angular momenta carried by up- and down-quarks of the nucleon is obtained as $J_u + J_d/2 = 0.49 \pm 0.17 \text{(exp)} / 2$. However, the double-distribution model of [5] cannot explain all existing DVCS data.

The nuclear-mass dependence of beam-helicity azimuthal asymmetries has been measured for targets ranging from hydrogen to xenon [6]. For hydrogen, krypton and xenon, data were taken with both beam charges. For both DVCS and BH, coherent scattering occurs at small values of $-t$ and rapidly diminishes with increasing $|t|$. Coherent and incoherent-enriched samples are selected according to a $-t$ threshold that is chosen to vary with the target such that for each sample approximately the same kinematic conditions are obtained.

Figure 1: The amplitudes of the beam charge asymmetry extracted from hydrogen data (black bullets) [4]. The error bars (bands) represent the statistical (systematic) uncertainties. The curves are predictions of a double-distribution GPD model [5].

$F_{\pi} = 94 \text{MeV}$
Figure 2: The amplitudes of the beam-helicity asymmetry from the interference term on the unpolarized hydrogen target [4]. The error bars (bands) represent the statistical (systematic) uncertainties. The curves are predictions of a double-distribution GPD model [5].

for all target types. The nuclear-mass dependence of the beam-charge and beam-helicity azimuthal asymmetries is presented separately for the coherent and incoherent-enriched samples in Fig. 3 (left). The cos\(\phi\) amplitude of the beam-charge asymmetry is consistent with zero for the coherent-enriched samples for all three targets, while it is about 0.1 for the incoherent-enriched samples. The sin\(\phi\) amplitude of the beam-helicity asymmetry shown in Fig. 3 (right) has values of about −0.2 for both the coherent and incoherent-enriched samples. No nuclear-mass dependence of the beam-charge and beam-helicity asymmetries is observed within experimental uncertainties. This is in agreement with models that approximate nuclear GPDs by nucleon GPDs neglecting bound state effects. The data do not support the enhancement of nuclear asymmetries compared to the free proton asymmetries for coherent scattering on spin-0 and spin-1/2 nuclei as anticipated by various models [7, 8, 9]. They also contradict the predicted strong \(A\) dependence of the beam-charge asymmetry resulting from a contribution of meson exchange between nucleons to the scattering amplitude [9].

5 The HERMES recoil detector

In order to ensure exclusivity and reduce the background from the associated BH process, a new recoil detector was installed at HERMES in winter of 2005-2006. The recoil detector consists of a silicon strip detector, a scintillating fiber tracker and a photon detector located in a 1 T solenoidal magnetic field. The main task of the photon detector is to detect photons from \(\pi^0\) decay and thereby suppress the contribution from associated \(\Delta^+\) production. The recoil detector was in operation during the high luminosity run of HERA using unpolarized hydrogen and deuterium targets from 2006 to 2007. A large amount of data was collected in these two years and is being analyzed.
Figure 3: Nuclear-mass dependence of the $\cos \phi$ amplitude of the beam-charge asymmetry (left) and of the $\sin \phi$ amplitude of the beam-helicity asymmetry (right) for the coherent-enriched (upper panels) and incoherent-enriched (lower panels) data samples. The inner (full) errors bar represent the statistical (total) uncertainties.

6 Conclusion

HERMES has measured a significant first cosine moment of the beam-charge asymmetry and first sine moment of the charge dependent beam-helicity asymmetry in DVCS from hydrogen and deuterium targets. The statistical precision of the data allows us to provide constraints on theoretical calculations. The unknown contribution from the associated process can be understood from data taken with the recoil detector. A model-dependent constraint on the total angular momenta carried by up- and down- quarks of the nucleon is obtained by comparing GPD model calculations with the measured BCA and TTSA. Beam-charge and beam-helicity asymmetries have been measured for targets ranging from hydrogen to xenon.

No nuclear-mass dependence of the asymmetry amplitudes is observed within experimental uncertainties. The obtained results provide constraints on nuclear GPD models.

References