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Deeply Virtual Compton Scattering at Jefferson Lab, Results and Prospects

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Recent results from the Deeply Virtual Compton Scattering (DVCS) program at Jefferson Lab will be presented. Approved dedicated DVCS experiments at 6 GeV and plans for the 12 GeV upgrade will be discussed.

1. INTRODUCTION

The recently developed formalism of "Generalized Parton Distributions" (GPDs) [1–3] showed that information on quark-quark correlations, the transverse quark momentum distribution, and contributions of correlated quark-antiquark pairs (mesons) to the nucleon wave function can be obtained in hard exclusive leptoproduction experiments. GPDs provide a unifying framework for the interpretation of an entire set of fundamental quantities of hadronic structure, such as, the vector and axial vector nucleon form factors, the polarized and unpolarized parton distributions, and the spin components of the nucleon due to orbital excitations.

Deeply Virtual Compton Scattering (DVCS) is one of the key reactions to determine the GPDs experimentally, and it is the simplest process that can be described in terms of GPDs. The dominance of the handbag diagram and the behavior of the reduced forward cross section as $1/Q^4$ (scaling regime) is expected to be reached at lower Q^2 than in the case of deeply exclusive meson production. This is supported by measurements of the $\gamma^*\gamma\pi^0$ form-factor in e^-e^+ collisions [4].

One of the first experimental observation of DVCS was obtained from the recent analysis of CLAS data with a 4.2 GeV polarized electron beam in a kinematical regime near $Q^2 = 1.5$ GeV^2 and $x_B = 0.22$ [5]. New measurements at higher energies are currently being analyzed, and dedicated experiments are planned. The high luminosity available for these measurements will make it possible to determine details of the Q^2, x_B, and t dependences of GPDs.

2. FIRST OBSERVATION OF EXCLUSIVE DVCS WITH THE CLAS DETECTOR

The DVCS/Bethe-Heitler (BH) interference has recently been measured using the CEBAF Large Acceptance Spectrometer in Hall B at Jefferson Lab [5]. The data were collected as a by-product of the 1999 run with a 4.25 GeV polarized electron beam. At energies above 4 GeV, the CLAS acceptance covers a wide range of kinematics in the deep inelastic scattering domain ($W \geq 2$ GeV and $Q^2 \geq 1$ GeV^2). The open acceptance

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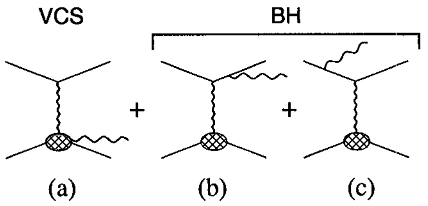

Figure 1. Feynman diagrams for VCS and Bethe-Heitler processes contributing to the amplitude of $ep \to ep\gamma$ scattering.

of CLAS and the use of a single electron trigger ensures event recording for all possible final states. This experiment measures DVCS via the interference with the Bethe-Heitler (figure 1. At beam energies accessible at Jefferson Lab, the BH contribution in the cross section is predicted to be several times larger than the DVCS contribution in most regions of the phase space. The dominant BH process can be turned into an advantage by using a longitudinally polarized electron beam: one can measure the helicity-dependent interference term that is proportional to the imaginary part of the DVCS amplitude. In this case the pure real BH contribution is subtracted out in the cross section difference.

For the present DVCS analysis, electron and proton were both detected in the CLAS detector, the reaction $\vec{e}p \to epX$ was studied and the number of single photon final states was extracted by fitting the missing mass (M_X^2) distributions. The beam spin asymmetry was then calculated as:

$$BSA = \frac{1}{P_e}\frac{\left(N_\gamma^+ - N_\gamma^-\right)}{\left(N_\gamma^+ + N_\gamma^-\right)} \tag{1}$$

Here P_e is the beam polarization and, $N_\gamma^{+(-)}$ is the extracted number of $\vec{e}p \to ep\gamma$ events at positive (negative) beam helicity. The resulting ϕ-dependence is shown in figure 2. A fit to the function

$$F(\phi) = A\sin\phi + B\sin 2\phi \tag{2}$$

yields $A = 0.217 \pm 0.031$ and $B = 0.027 \pm 0.022$. If the handbag diagram dominates, as expected in the Bjorken regime, B should vanish and only the contribution from transverse photons should remain, described by the parameter A. The GPD analysis including twist-3 contribution shows sensitivity of these data to $\bar{q}Gq$ correlations [6].

3. DEDICATED DVCS EXPERIMENTS AT JEFFERSON LAB

There are two dedicated DVCS experiments planned to run using the 6 GeV polarized electron beam. Both experiments plan to detect all three particles in the final state, the scattered electron, the recoil proton, and the photon.

The first experiment E00-110 [7] is a Hall A experiment which is expected to run in 2003. The DVCS beam spin asymmetries and cross section differences will be measured

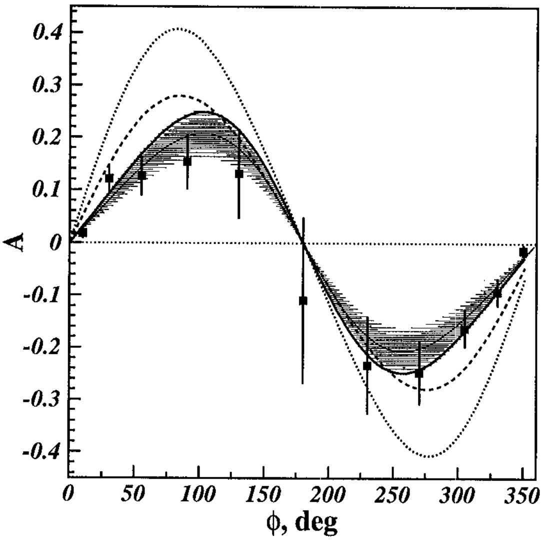

Figure 2. ϕ dependence of the $\vec{e}p \rightarrow ep\gamma$ beam spin asymmetry at 4.25 GeV. Data are integrated over the range of Q^2 from 1 to 2 GeV^2, x_B from 0.13 to 0.35 (with the condition $W > 2$ GeV) and $-t$ from 0.1 to 0.3 GeV^2. The shaded region is the range of the fit function A(ϕ) defined by statistical and systematical uncertanties. The curves are model calculations according to Ref. [6].

at three Q^2 intervals, for a fixed interval of x_B. The experiment will provide a precise check of the Q^2 dependence of the $ep \rightarrow ep\gamma$ cross section differences (for different beam helicities).

The second experiment E01-113 [8] is a dedicated CLAS DVCS experiment. The main goal of this experiment is to measure the t, ϕ, and x_B dependence of the beam spin asymmetry for several fixed Q^2 bins. This quantity is sensitive to the model description of the GPDs. This will be the first time this dependence will be studied with high sensitivity using the DVCS process. A second goal will be to extract the helicity-dependent cross section difference, which directly determines the imaginary part of the DVCS amplitude.

Figure 3 shows examples of the expected CLAS results, the t and ϕ dependence of the cross section and of the beam spin asymmetry, for three bins in Q^2 and x_B. Expected data points are shown only for $Q^2 = 2$ GeV^2 and $x_B = 0.35$. Comparison with different models for the ξ-dependence of the GPDs is made, together with a first estimation of the twist-3 effects for this process.

The results of these two experiments, Hall A and CLAS, on the $\vec{e}p \rightarrow ep\gamma$ cross section will allow tests of the Q^2-dependence to check the scaling behavior. As CLAS covers a broad kinematic range, we will be able to test the Q^2 dependence for different x_B. This will verify that we are in a regime where a direct interpretation of the results in terms of GPDs is possible. Observation of significant scaling violations would provide important input for the analysis in terms of higher twist effects.

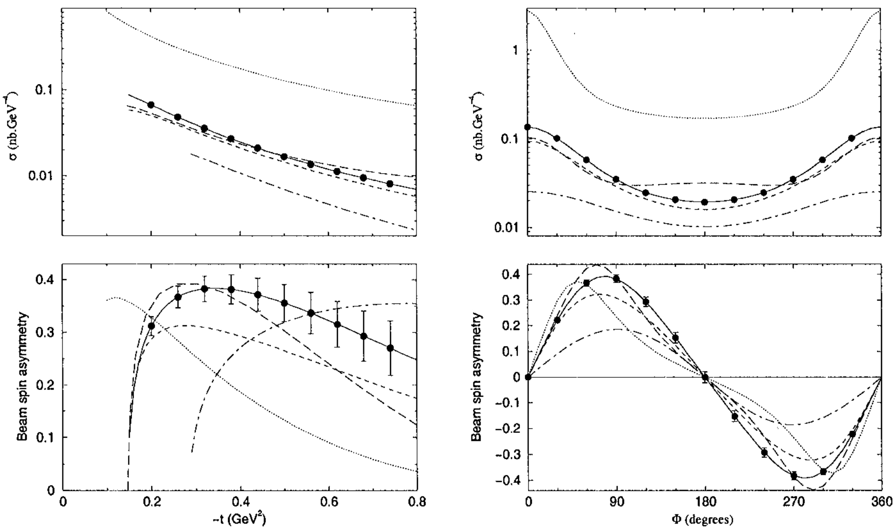

Figure 3. The left graph shows the t-dependence of $\vec{e}p \rightarrow ep\gamma$ observables at 6 GeV, for ϕ = 90°and Q^2 = 1 GeV^2, x_B = 0.22 (dotted curve), Q^2 = 2 GeV^2, x_B = 0.35 (solid), Q^2 = 3.6 GeV^2, x_B = 0.45 (dot-dashed), calculated with the ξ-dependent GPDs of Refs. [9,10]. From the same references, the ξ-independent version is also shown (dashed), and from Ref. [11] the calculation including twist-3 effects (long-dashed), both at Q^2 = 2 GeV^2. The right graph shows the ϕ-dependence of $\vec{e}p \rightarrow ep\gamma$ observables at 6 GeV, for $t = -0.325$ GeV^2. The points illustrate the expected statistical accuracy at Q^2 = 2 GeV^2.

4. CEBAF 12 GeV UPGRADE AND DVCS PROGRAM

The study of GPDs via deeply exclusive reactions is one of the main research programs driving the CLAS upgrade to 12 GeV [12][13].

The DVCS cross section and spin asymmetries will be measured in a large range of kinematical bins, simultaneously. Figure 4 illustrates the power of such measurements, showing the expected statistical accuracy of the data, and an example of their binning. In the figure, simulated data on the beam spin asymmetry are shown in the 56 bins of x_B, Q^2, and t (a total of 1064 points). The outer horizontal scale corresponds to x_B, divided into 4 bins, shown by solid lines. The outer vertical scale represents Q^2. The Q^2 bins shown as rows of asymmetry distributions. Larger bins at higher Q^2 are to compensate for the fast drop of the cross section. In each row, several beam spin asymmetry distributions as a function of $\phi_{\gamma\gamma*}$ (running from 0° to 360°) correspond to different t bins. The average value of $-t$ is shown in the upper corner of each plot.

Figure 5 shows more clearly the accuracy of such a measurement and its sensitivity to the models in 2 selected bins, $x_B = 0.35$ and $-t = 0.3$ (GeV/c)^2, for $Q^2 = 2.75$ (GeV/c)^2 in figure 5.a, and for $Q^2 = 5.4$ (GeV/c)^2 in figure 5.b. As an input to the simulation cross sections calculated in Ref.[10] based on Ref. [9] have been used. Different curves in the figure correspond to different model assumptions. One sees sufficient sensitivity for the separation of models at both Q^2.

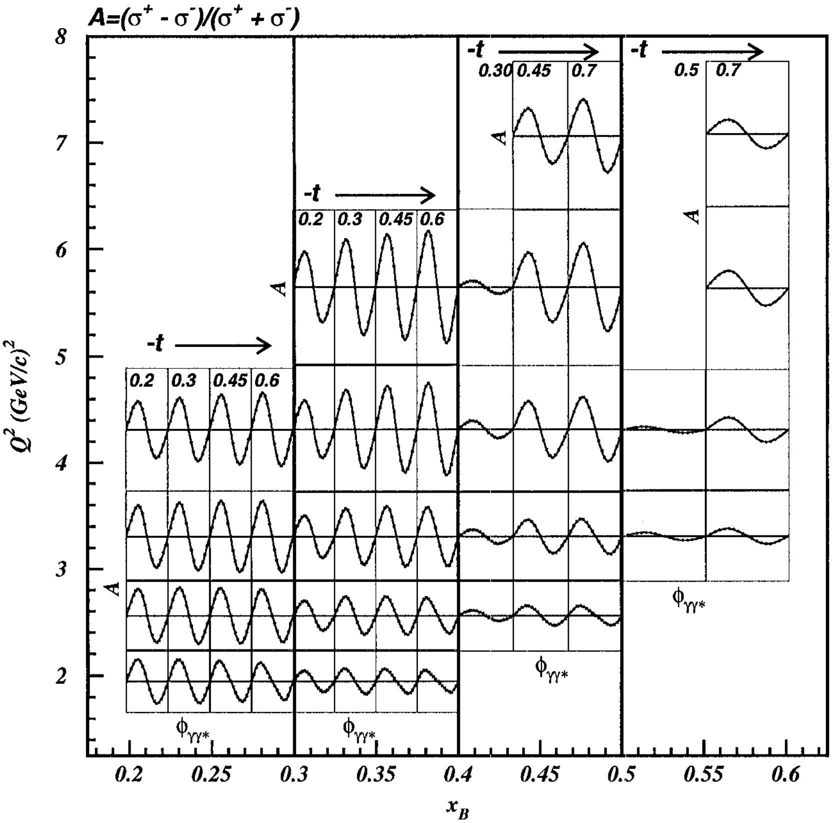

Figure 4. Kinematical coverage for beam spin asymmetry measurements in DVCS. Possible binning of future data is shown.

5. SUMMARY

A first measurement of the beam spin asymmetry in the exclusive electroproduction of real photons in the deep inelastic regime was presented. We see a clear asymmetry, as expected from the interference of the DVCS and BH processes. It has been shown that our results can be accomodated within a GPD analysis [6]. This supports the expectations that DVCS will allow access to GPDs at relatively low energies and momentum transfers. This opens up a new avenue for the study of nucleon structure which is inaccessible in inclusive scattering experiments. Dedicated DVCS experiments at 6 GeV electron beam energy are planned, which will allow significant expansion of the Q^2 and x_B range covered in these studies. The high luminosity available for these measurements will make it possible to map out details of the Q^2, x_B, and t dependences of GPDs.

The CEBAF 12 GeV upgrade will allow a breakthrough program, in the study of nucleon structure via deeply virtual exclusive reactions, to be carried out with unprecedented precision.

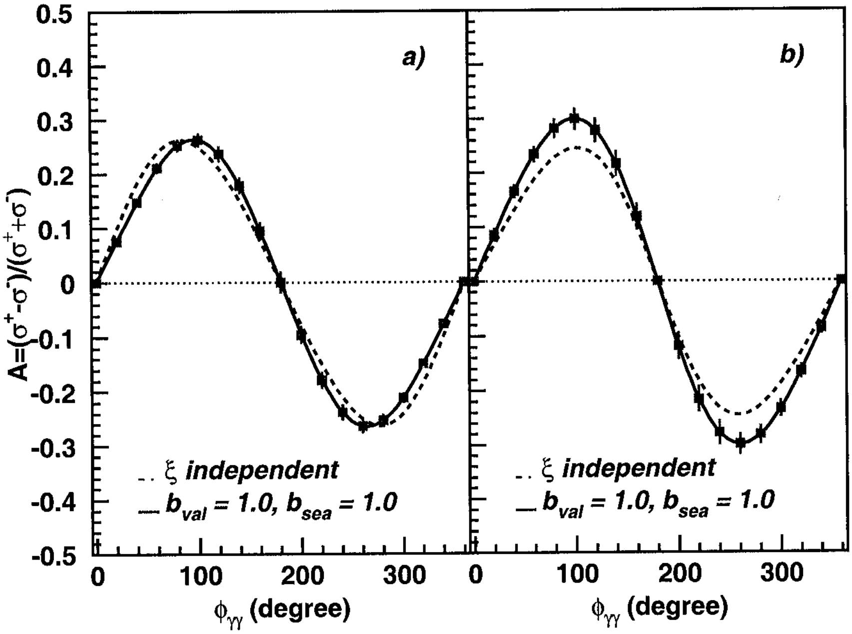

Figure 5. Expected data on the beam spin asymmetry at the kinematics $x_B = 0.35$ and $-t = 0.3$ (GeV/c)^2, and a) $Q^2 = 2.75$ (GeV/c)^2 and b) $Q^2 = 5.4$ (GeV/c)^2. Expected statistical errors are shown only. Data are simulated assuming 2000 hours of running at a luminosity 10^{35} cm^{-2} sec^{-1} with the upgraded CLAS detector.

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