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**EXPERIMENTAL STATUS DVCS  $EP \rightarrow EP\gamma$   
AND  $EN \rightarrow EN\gamma$  AT JEFFERSON LAB-HALL A**

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The experiments E00-110 and E03-106[1] propose to measure the Deep Virtual Compton Scattering process (DVCS)  $ep \rightarrow ep\gamma$  and  $en \rightarrow en\gamma$  in Hall A at Jefferson Lab with a 5.75 GeV longitudinally polarized electron beam. The exclusivity requires the High Resolution Spectrometer of the Hall A for the scattered electron ( $\frac{\Delta p}{p} = 10^{-4}$ ), an electromagnetic calorimeter for the real photon ( $\frac{\sigma_E}{E} < 5\%$ ) and a scintillator array for the third particle. A 1GHz sampling system allows one to deal with pile-up as expected from running detectors at small angles and high luminosity  $\mathcal{L} = 10^{37} \text{cm}^{-2} \text{s}^{-1}$ . We will describe the apparatus and will explain the method to extract the GPDs and evaluate the contributions from higher twists from the measurement of the cross-section difference.

## 1. Introduction

In the nineties, a new theoretical framework has been proposed namely the Generalized Parton Distributions (GPDs). They provide an intimate connection between the ordinary parton distributions and the elastic form factors and therefore contain a wealth of information on the quark-gluon structure of the nucleon. The QCD factorization theorems[2] have established that GPDs can be measured via exclusive reactions in the so called deep virtual limit (fixed Bjorken variable  $x_B, Q^2 \gg \Lambda_{QCD}^2, Q^2 \gg -t, t = (p' - p)^2$ ,  $p$  and  $p'$  initial and recoil nucleon four-vectors). The simplest exclusive process to study that can be described in terms of GPDs is the Deeply Virtual Compton Scattering (DVCS)  $\gamma^* N \rightarrow \gamma N$ , measured in the exclusive electroproduction reaction  $eN \rightarrow eN\gamma$  in deep inelastic scattering kinematics (DIS). X. Ji[3] suggested using DVCS to get information about GPDs which generalize the concept of parton distributions found in DIS. The DVCS amplitude can be factorized in a soft part containing the non perturbative physics and described by the GPDs and a parton process calculable via

perturbative QCD [2, 4]. The soft structure of the nucleon is parametrized by four functions known as the GPDs:  $E, H, \tilde{E}$  and  $\tilde{H}$ .

## 2. GPD's measurement

The exclusive electroproduction  $eN \rightarrow eN\gamma$  involve two processes. The real photon of the final state can come from the DVCS process or can be radiated by the lepton in the Bethe Heitler process. This second process is completely calculable at small  $t$ . The interference between these two processes dominates in the difference of cross-section between longitudinally polarized electrons of opposite helicities and is proportional to the imaginary part of the DVCS amplitude amplified by the full magnitude of the BH amplitude. The helicity structure of DVCS gives rise to an angular dependence on the variable  $\varphi$ , the angle between the leptonic plane ( $e, e'$ ) and the hadronic plane ( $\gamma^*, \gamma$ ). The specific observable we propose to measure is this cross-section difference as a function of  $\varphi$ [5]. This observable is non zero only if the emitted photon is out of the electron scattering plane ( $\varphi \neq 0$ ) and its full expression is given by [6]:

$$\frac{d\vec{\sigma}}{dx_B dy dt d\varphi} - \frac{d\overleftarrow{\sigma}}{dx_B dy dt d\varphi} = \Gamma(x_B, y, t, \varphi)(A \sin \varphi + B \sin 2\varphi)$$

$\Gamma(x_B, y, t, \varphi)^a$  kinematical factor from BH propagators.

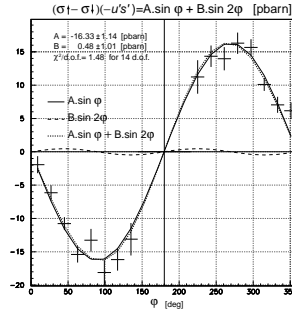


Figure 1. Expected cross-section difference multiplied by a kinematical factor corresponding to the BH propagators as a function of  $\varphi$  and extraction of A and B coefficients for 200 hours of beam time with a luminosity  $\mathcal{L} = 10^{37} \text{ cm}^{-2} \text{ s}^{-1}$ , a beam polarization of 70% and the  $Q^2 = 2.5 \text{ GeV}^2$  setting on hydrogen target.

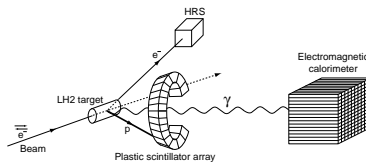
<sup>a</sup> $y = \frac{k-k'}{k}$ , where  $(k, k')$  energies  $(e, e')$

The goal of these two experiments will be to provide the first checks of the  $Q^2$ -dependent scaling of the DVCS amplitude, as well as to evaluate the linear combination of the GPDs (A coefficient) and study the higher-twist effects (B coefficient). We plan to measure the helicity dependent cross-section for three kinematics using a 5.75 GeV beam, ranging from  $Q^2 = 1.5$  to  $2.3 \text{ GeV}^2$  at fixed  $x_B \sim 0.35$  in order to study the  $Q^2$  dependence of A and B. At leading twist, this asymmetry reduces to the  $\sin\varphi$  term for which the coefficient is directly linked to the GPDs H,E and  $\tilde{H}$ :

$$A = F_1(t) \cdot H + \frac{x_B}{2-x_B} (F_1(t) + F_2(t)) \cdot \tilde{H} - \frac{t}{4M^2} F_2(t) \cdot E$$

where  $F_1(t)$  and  $F_2(t)$  are the Dirac and Pauli form factors. In the proton case, the leading term is  $F_1(t) \cdot H$ . Indeed,  $F_1(t)$  and H are large for the proton, unlike  $F_2(t)$ ,  $\tilde{H}$  and E which turn out to be much smaller. In the neutron case, the  $F_1(t)$  form factor is much smaller than  $F_2(t)$ , unlike in the proton's case. Then the leading term becomes  $-\frac{t}{4M^2} F_2(t) \cdot E$  since  $\tilde{H}$  is small. The neutron DVCS experiment is complementary to the proton's. With both experiments, one will have the first accurate handle on the three GPDs H, $\tilde{H}$  and E which is basically unknown and unconstrained. The cross-section difference can be directly related to GPDs but its measurement is more complicated than trying to access the single spin asymmetry where the detectors efficiency cancel out.

### 3. Experimental setup



A longitudinally polarized electron beam will be used, along with the 15 cm Hall A hydrogen cryotarget for DVCS on proton. The Hall A electron spectrometer will be used to detect the scattered electrons with a high resolution  $\frac{\Delta p}{p} = 10^{-4}$ . The scattered photon will be measured by an electromagnetic calorimeter. It consists of 132 blocks of lead fluoride, each with dimension 30 mm x 30 mm x 184 mm. Lead fluoride is very dense ( $\rho = 7.66 \text{ g/cm}^3$ ), with a short radiation length ( $X_0 = 0.95 \text{ cm}$ ) and a small Moliere radius ( $r_M = 2.22 \text{ cm}$ ), which allows to built a compact calorime-

ter. The calorimeter will be centered in the direction of the virtual photon and placed 110 cm from the target. The resolution is  $\frac{\sigma_E}{E}$  is less than 5% for 3 GeV DVCS photons energy. The recoil protons will be detected in a 100 element plastic scintillator array in order to ensure the exclusivity of the reaction. This array is matched to the out-of-plane acceptance ( $\varphi \neq 0$ ) required to measure the beam helicity asymmetry in deeply virtual kinematics. The array subtends polar angles 18 to 38 degrees in five rings around the direction of the virtual photon. Each ring is divided into 20 elements that together subtend azimuthal angles from 45 to 315 degrees (gap for exit beam pipe). The ring of segmented plastic scintillators is located about 60 cm from the target (picture above). Each block of the calorimeter and each scintillator is coupled to a photomultiplier. Due to the proximity of the detectors from the target and the beam pipe, high singles rate  $\sim$ MHz are expected. This induces pile up and limits the luminosity. To solve that, the calorimeter and proton array information are recorded using a novel system: Analog Ring Samplers. Each channel of the detectors is continuously sampled and stored on a 128-capacitor ring at a frequency of 1 GHz. The sampling allow to perform a shape analysis and subtract the pile up events from the DVCS events. Solving this pile up problem will allow us to reach a higher luminosity and perform the experiment in a reasonable time scale.

DVCS on the neutron will use an improved version of the proton E00-110 experimental setup. First, a 15 cm liquid deuterium target as a quasi-free neutron target will be used. The neutron detection and the proton/neutron discrimination will be achieved by adding iron shielding and a charged particle tagger in front of the scintillator array. The tagger system consists in a 2 to 3 cm thick scintillator paddles placed in front of a scintillator blocks of the proton array, allowing to identify charged particles with a very high efficiency while having a low efficiency to neutral particles.

#### 4. Physics analysis

The aim is to extract the values of the A and B coefficients corresponding to the twist-2 and higher-twist contributions which appear in the difference of cross-sections for opposite helicities:

$$\frac{d\vec{\sigma}}{dx_B dy dt d\varphi} - \frac{d\overleftarrow{\sigma}}{dx_B dy dt d\varphi} = \Gamma(x_B, y, t, \varphi)(A \sin\varphi + B \sin 2\varphi)$$

The  $\sin\varphi$  coefficient has no  $Q^2$  dependence and the  $\sin 2\varphi$  is expected to have  $1/Q$  dependence. We will extract the A and B coefficients using the

following method. The difference between the number of counts binned in  $\varphi$  and  $t$  for opposite helicities  $\vec{N}(\Delta\varphi_i, \Delta t_j) - \overleftarrow{N}(\Delta\varphi_i, \Delta t_j)$  corresponds to the cross-section difference convoluted by the experimental efficiency:

$$\begin{aligned} & \mathcal{L} \cdot \int_{\Delta\varphi_i, \Delta t_j} \left( \frac{d\vec{\sigma}}{dx_B dy dt d\varphi} - \frac{d\overleftarrow{\sigma}}{dx_B dy dt d\varphi} \right) \cdot \varepsilon_{ff}(x_B, y, t, \varphi) dx_B dy dt d\varphi \\ &= \mathcal{L} \cdot A(\bar{x}_B, \bar{t}) \int_{\Delta\varphi_i, \Delta t_j} \sin\varphi \cdot \Gamma(x_B, y, t, \varphi) \cdot \varepsilon_{ff}(x_B, y, t, \varphi) dx_B dy dt d\varphi \\ &+ \mathcal{L} \cdot B(\bar{x}_B, \bar{t}, \bar{Q}^2) \int_{\Delta\varphi_i, \Delta t_j} \sin 2\varphi \cdot \Gamma(x_B, y, t, \varphi) \cdot \varepsilon_{ff}(x_B, y, t, \varphi) dx_B dy dt d\varphi \\ \vec{N} - \overleftarrow{N} &= \mathcal{L} \cdot A(\bar{x}_B, \bar{t}) \cdot \mathcal{I}_1(\Delta\varphi_i, \Delta t_j) + \mathcal{L} \cdot B(\bar{x}_B, \bar{t}, \bar{Q}^2) \cdot \mathcal{I}_2(\Delta\varphi_i, \Delta t_j) \end{aligned}$$

- $\mathcal{I}_1(\Delta\varphi_i, \Delta t_j)$  and  $\mathcal{I}_2(\Delta\varphi_i, \Delta t_j)$  computed from Monte Carlo,
- $N(\Delta\varphi_i, \Delta t_j)$  collected counts in the bin(i,j) in  $(\varphi, t)$ ,
- $\varepsilon_{ff}(x_B, y, t, \varphi)$  detectors efficiency and  $\mathcal{L}$  the luminosity.

For each bin in the variable  $t$ , a system of linear equations (one for each  $\varphi$  bin) is built from which the A and B coefficients are extracted.

## 5. Conclusion

The Generalized Parton Distributions have just been tackled by recent measurements which have confirmed that Deeply Virtual Compton Scattering experiments can be achieved at existing facilities and especially Jefferson Lab at moderate  $Q^2$ [7]. The first dedicated experiment in Hall A will extract the helicity dependent DVCS cross-sections on the proton in the  $Q^2$  range 1.5-2.3  $GeV^2$ . However, proton experiment can only constrain or extract the H and  $\tilde{H}$  GPDs. A neutron DVCS experiment will be mostly sensitive to the least known of GPDs: E, essential for the understanding of the nucleon structure and to access the total angular momentum carried by the quarks in the nucleon in X.Ji's sum rule[3].

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