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STUDY OF BEAM SPIN ASYMMETRY IN EXCLUSIVE Π° PRODUCTION

Ian Howley and Harut Avagyan

ABSTRACT

Describing and understanding atomic nuclei is a puzzle that has intrigued scientists for decades. Approximately ten years ago, a description of nucleon structure, referred to as Generalized Parton Distribution (GPD), was introduced. GPDs are a way of describing scattering and production processes in a single framework. Deeply Virtual Compton Scattering (DVCS) is a process that scatters a photon from a proton and detects a scattered electron, a proton, and one photon in the final state. From DVCS, GPDs can be extracted in order to lead us to a more complete picture of nucleon structure. The focus of this study is to understand the beam spin asymmetry (BSA) of the neutral π° meson, a main source of background during the DVCS process. To calculate the BSA, the number of π° events with positive helicity (spin) and negative helicity were counted by integrating histograms with Gaussians fits. It is shown that there is a significant non-zero BSA in production of exclusive π°, namely 0.0655±0.0022. In the analysis of previous experiments, the BSA of π° was assumed to be zero and therefore ignored. Now, future analyses of DVCS data may incorporate this evidence of BSA. A deeper understanding of background processes (π°) in the DVCS will allow precision measurements of GPDs, providing new insight concerning the structure of nucleons.

INTRODUCTION

Since the discovery of quarks in the 1960s, research in nuclear physics has been focused on understanding the role quarks play in nucleon structure. Early theories simplified the momentum distribution of quarks to a one-dimensional model. By limiting quark distributions to the longitudinal momentum (in the infinite momentum frame), theorists made relatively accurate predictions about the complex structure of the proton. Each quark carries a fraction of the total momentum of the proton, represented by x (Figure 1a). Many studies were conducted concerning form factors, which are descriptions of the charge distribution inside a proton (Figure 1b). Combining these methods allow for a three dimensional model of nucleon structure (Figure 1c) [1].

Deeply virtual Compton scattering (DVCS) is the cleanest process available to study general parton distributions (GPDs). The DVCS processes follow the pattern $ep \rightarrow e'p'\gamma$. However, other processes such as the Bethe-Heitler process yield the same result, except that the photon is emitted by the incoming or outgoing electron, rather than as a result of proton excitation (Figure 2). The decay of π° ($ep \rightarrow e'p'\gamma\gamma$) is another process which creates extraneous events that must be separated from desirable events when observing the DVCS process. An understanding of background processes in the exclusive photon production allows measurement of DVCS asymmetry with a high degree of accuracy. Therefore, an asymmetry in the background must be taken into account in order to ensure the quality of the results.

The Asymmetry

The number of photons in the exclusive photon sample from π° and their asymmetry are the two most important factors in DVCS asymmetry measurement. Also, wide acceptance detectors, such as the Continuous Electron Beam Accelerator Facility (CEBAF) Large Acceptance Spectrometer (CLAS) at Jefferson Laboratory (JLab), require a wide range of kinematics to study the asymmetry, $A_{LU,}$ where the beam is polarized (subscript L) and the target is unpolarized (subscript U). Cross section dependency on the azimuthal angle ϕ, defined as the angle between the scattering and production planes (Figure 3), gives rise to observable asymmetries. In order to understand the asymmetries' dependence on this angle ϕ, the general form of a cross section is used:

$$\sigma = \sigma_0 + \lambda \sigma_1 \sin\varphi . \qquad (1)$$

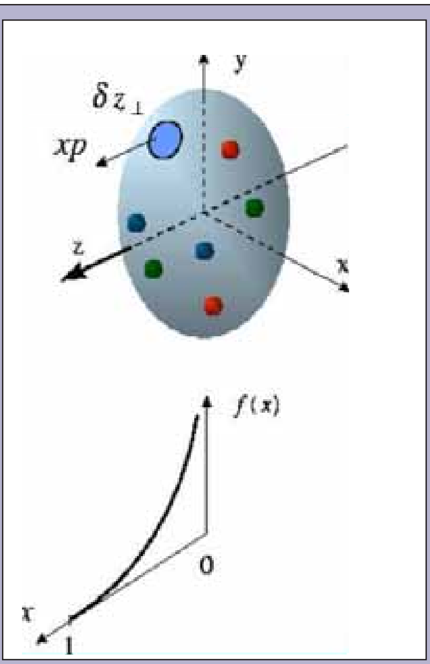

Figure 1a. Longitudinal Momentum Distribution; at large x, the probability is small since it is unlikely that one quark will carry all the momentum for the proton.

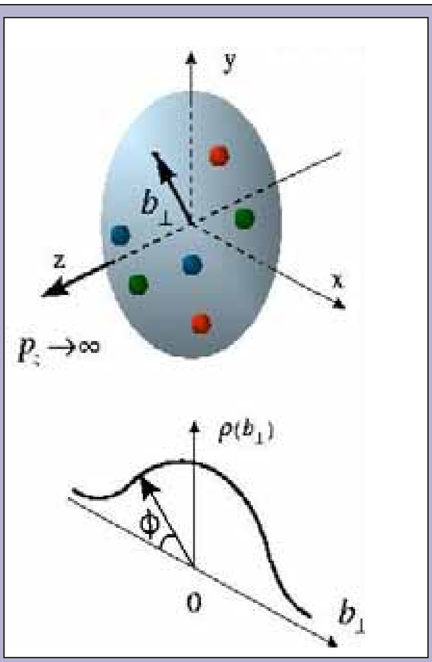

Figure 1b. Form factors showing the charge distribution inside the proton.

Here, σ is the probability of a π° being produced, λ is the helicity and ϕ is the azimuthal angle. σ_0 and σ_1 define the spin independent and spin dependent portions of the cross section, respectively, and are the primary parameters to be determined. Helicity is the projection of the spin of a particle with respect to the direction it's traveling. Electrons, including those at CEBAF, can have helicity '+' corresponding to positive beam polarization or helicity '-' corresponding to negative polarization. The beam polarization changes every 33ms and allows for more degrees of freedom while measuring the kinematic distribution inside the proton. Equation 1 then becomes:

$$\sigma^+ = \sigma_0 + \sigma_1 \sin\varphi \quad \text{and} \quad \sigma^- = \sigma_0 - \sigma_1 \sin\varphi, \qquad (2)\ (3)$$

for positive and negative beam polarizations respectively. The asymmetry is defined as:

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}, \qquad (4)$$

which, when equations 2 and 3 are substituted in, yields:

$$A = \frac{\sigma_1}{\sigma_0} \sin\varphi . \qquad (5)$$

From equation 5 it is clear that the ratio $\frac{\sigma_1}{\sigma_0}$ is the amplitude of sinϕ and the most important quantity of this experiment. Since the detector detects particles within a certain acceptance (and efficiency), the number of events, N+/-, can be written as the product of the detectors acceptance, a, and the cross section:

$$N^{+/-} = a^{+/-} \sigma^{+/-} . \qquad (6)$$

The acceptance of the detector accounts for its ability to detect particles. Factors that limit the acceptance of the detector include areas where there is no detector (to allow room for superconducting magnets), very small angles, or even dead spots in the equipment itself. The factor a should be the same for both positive and negative

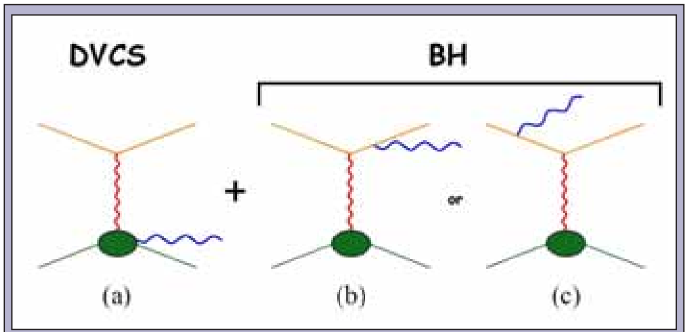

Figure 2. This figure shows how the three detected particle are the same (scattered electron, photon, and proton), but are not the result of the same process.

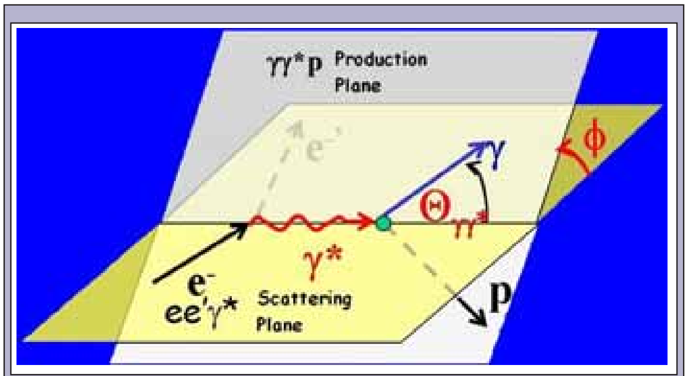

Figure 3. The Scattering and Production Planes.

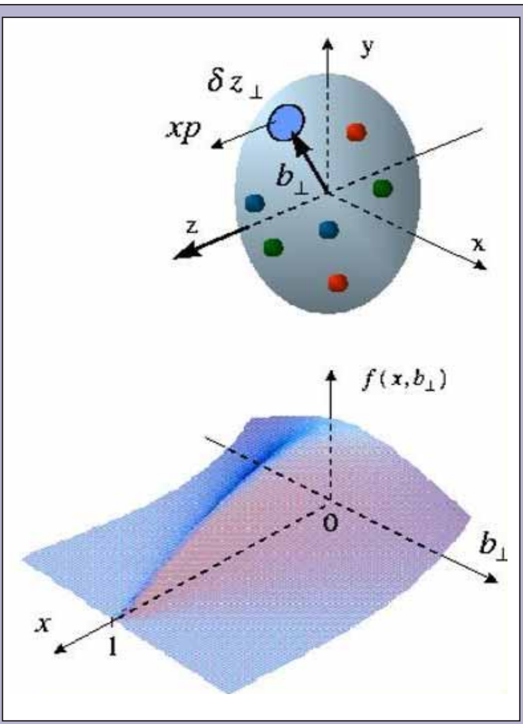

Figure 1c. Three dimensional model of quark distribution.

helicities so when equation 6 is substituted into equation 4 the form used for the calculation of asymmetry is found:

$$A_{LU} = \frac{N^+ - N^-}{N^+ + N^-}. \qquad (7)$$

Previous experiments have attempted to measure the ratio $\frac{\sigma_1}{\sigma_0}$ but have failed to produce a result with a reasonable degree of accuracy. In order for the accuracy of an experiment to increase to the point where the asymmetry is observed, a large number of $\pi°$ events must be detected. More recent DVCS experiments [2] [3] have relied on estimates of $\pi°$ background. Thanks to a new CLAS experiment, the $\pi°$ background can finally be measured.

The Experiment

The 5.776GeV CEBAF electron beam was aimed at a 2.5cm long liquid hydrogen target placed 66cm upstream from the CLAS center. The experiment, e1-DVCS gathered data during the period from March to May 2005. It operated with 80% beam polarization. Developed and installed in CLAS for the purpose of studying DVCS, the Inner Calorimeter's (IC) main goal is to detect particles produced at very small angles, 4°-15°. The 1.3cm x 1.3cm x 16cm IC consists of 424 crystals with Avalanche Photo Diodes (APDs) attached to the back of each crystal to record the light readout. The IC is placed inside CLAS very near the target which is surrounded by the superconducting magnet to protect from Møller background (Figure 4). When the $\pi°$ decays into two photons, they are detected by the IC and organized into events which are then able to be analyzed.

METHODS

Paw++, a data analysis software, was used to organize data and to create and fit all plots. The first major step to determine the $\pi°$ asymmetry is to calculate the number of detected events with positive helicity and the number of events with negative helicity. To ensure the data quality, cuts were made to the approximately 250,000 events in the data set. In addition to fiducial cuts, three particle identification cuts were made to (1) the invariant mass, Mγγ, (2) the missing mass of e'p'X, M_X, and (3) the scattering angle, θ'.

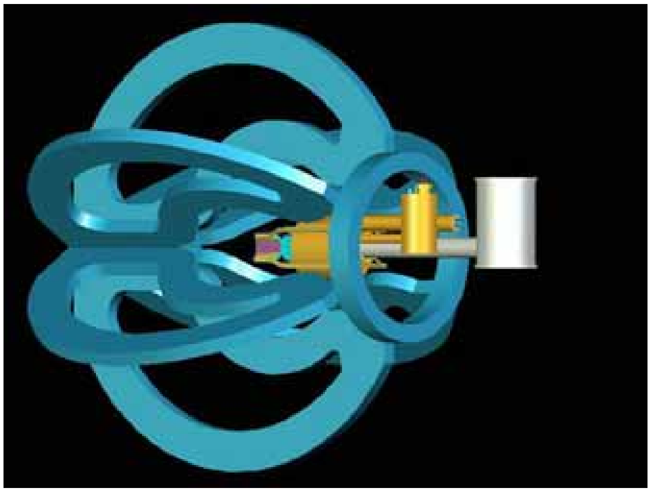

Figure 4. Schematic of CLAS detector with superconducting magnets (blue) and internal calorimeter (purple).

$$0.005 < \left| M_{\gamma\gamma}{}^2 \right| < 0.03 \qquad (8a)$$

$$\left| M_X{}^2 - M_\pi{}^2 \right| < 0.1 \qquad (8b)$$

$$\left| \theta' - \theta_\pi \right| < 1.5° \qquad (8c)$$

In equations 8b and 8c the subscript π represents the known or expected value. Also another cut was made on the measured energy inside the calorimeter, E_π^m.

$$\left| E_\pi^c - E_\pi^m \right| < 0.5\text{GeV} \qquad (8d)$$

$$E_\pi^c = E_{BEAM} + M - E_p - E_e \qquad (8e)$$

In order to calculate the number of events; the variables t, the momentum transfer to the proton, and ϕ were fixed and divided into bins four bins in t (.05<t<.85GeV) were created, each containing twelve bins in ϕ (0<ϕ<2π). For each of these 48 bins, the graph of Mγγ was plotted. A minimum of 125 events were required for each bin to assure the quality of the fit. Just as the $\pi°$ is a background to DVCS, there is background during $\pi°$ production. While this effect is much less than that of $\pi°$ on DVCS, it must be accounted for. A combination of Gaussian and linear functions was used for the graphs because a Gaussian curve fits the decay of π° properly and the linear terms accounts for the background (Figure 5). The parameters listed in Figure 5 are used to calculate the events.

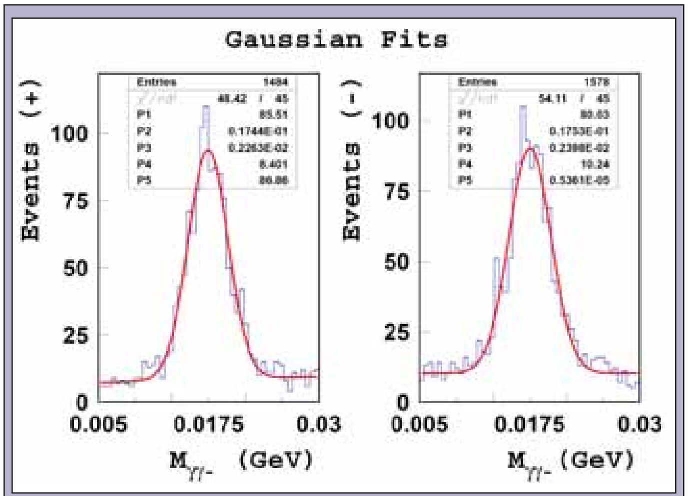

Figure 5. Two examples of the 96 graphs of Mγγ, positive helicity on the left, negative helicity on the right.

$$N_S = \int_{0.005}^{0.03} P_1 e^{-\frac{1}{2}\left(\frac{x-P_2}{P_3}\right)^2} dx, \tag{9}$$

is the integral of the Gaussian curve, and:

$$N_B = \int_{0.005}^{0.03} P_4 + P_5(x-P_3)dx \tag{10}$$

are the linear terms used for the background events. After performing the integral, in order to get the appropriate number of events, it was necessary to divide by the width of each bin, defined as:

$$\Delta d = \frac{(x_{\max} - x_{\min})}{n}, \tag{11}$$

where x_{max} and x_{min} define the boundaries of the graph, 0.03 and 0.005 respectively, and n represents the number of histogram bins under the curve, in this case 50. Also listed in Figure 5 is the number of events. This number of events cannot be used to calculate the BSA because they include the background. Rather, this number is used to check the accuracy of the integration. The background (equation 10) and signal (equation 9) events calculated from the integral are added together and compared to the total number of known events. In all 96 bins the difference between the known events and the calculated events was within 10%. This magnitude of error is acceptable because the calculation of the background, which is quite small and difficult to measure accurately, accounts for most of this discrepancy. However, an accurate measurement of the BSA can still be made. The final equations to calculate the events were:

$$N_S^{+/-} = \frac{\sqrt{2}P_1P_3}{\Delta d}\left(erf\left(\frac{x-P_2}{\sqrt{2}P_3}\right)\right)\Big|_{0.005}^{0.03} \tag{12}$$

where *erf(x)* is the error function defined as:

$$erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-y^2}dy, \tag{13}$$

and:

$$N_B = \frac{P_4}{\Delta d}x\Big|_{0.005}^{0.03} + \frac{P_5}{\Delta d}\left(\frac{x-P_3}{2}\right)^2 \Big|_{0.005}^{0.03}. \tag{14}$$

Once all of the events were known from the fit function (equation 12), the events in the four bins for each helicity were added together and the asymmetry was calculated from equation 7. Naturally, because of equation 5, a sine function was used to fit the asymmetry graph. Also, a standard calculation to find the error:

$$\Delta A_{LU} = \sqrt{\frac{2}{N^+ + N^-}}, \tag{15}$$

was used. The asymmetry is also plotted against the individual bins of t but must first be divided by the average polarization, 0.79 to account for the beam polarization not being 100%.

RESULTS

The key to unlocking the BSA was to measure the amplitude of the sinϕ term in equation 5. Figure 6 shows the amplitude of the asymmetry, which is 0.0655±0.0022, plotted against degrees. This is the first time this amplitude has been measured to be significantly non-zero. Also, for the first time, the t dependence of the BSA for π° was measured (Figure 7). No significant variation with t was observed within the error bars. The error no longer eclipses the size of the measured asymmetry as it has in previous experiments; instead the BSA of exclusive π° production is observed to within 3%.

CONCLUSIONS

For the first time, a non-zero BSA for exclusive π° production has been measured. With more than 250,000 events in the data set, this experiment well exceeded the results and accuracy of any previous experiment. The χ^2 values are reasonable, and the error in the asymmetry fit is small, 3%. The success of this experiment was due almost entirely to the detection of more π° events than ever before.

This result will be used for precision GPD measurements from the CLAS DVCS data. DVCS asymmetries will no longer include an estimated π° subtraction. With this result accurately measured, DVCS processes will be better understood, and in turn they will ultimately shed light on the structure of the proton.

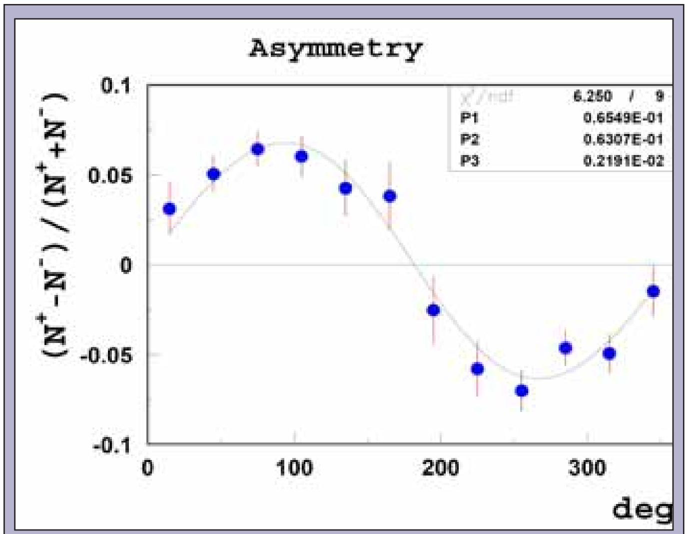

Figure 6. The azimuthal dependence of the asymmetry. P1 is the amplitude, P3 the error.

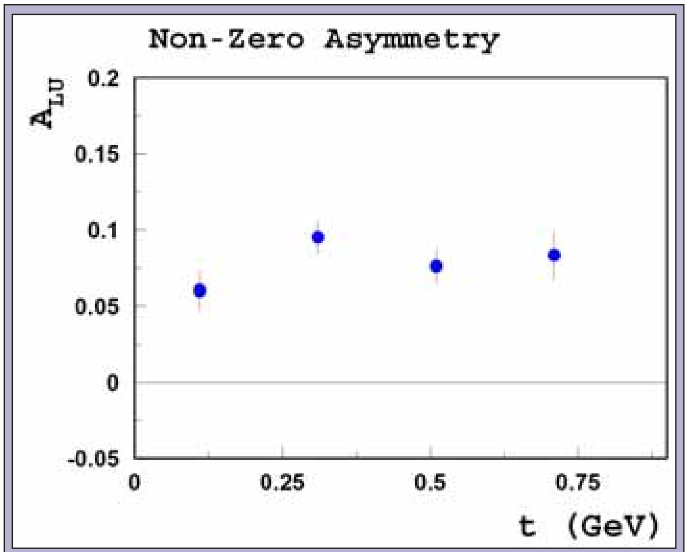

Figure 7. The asymmetry plotted against the momentum transfer of the proton shows no significant variation with t.

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